Polarized sources at RHIC.

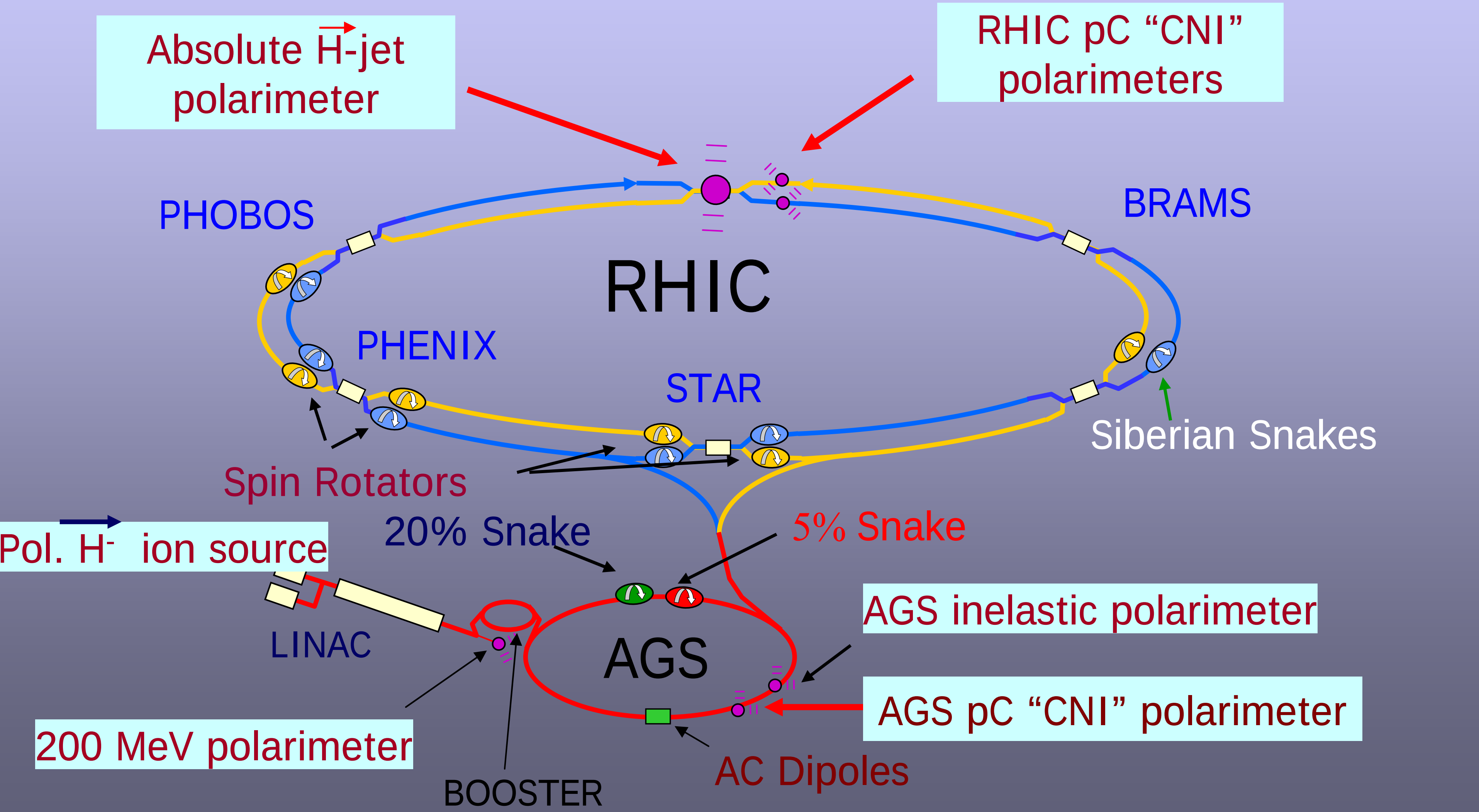
Anatoli Zelenski, CAD

- The RHIC polarized sources.
- R@D on polarized electron, pulsed OPPIS and $^{3}He^{++}$ ion sources.
- Polarized Sources,Targets and Polarimetry Workshop PSTP-2007 at BNL, September 10-14.

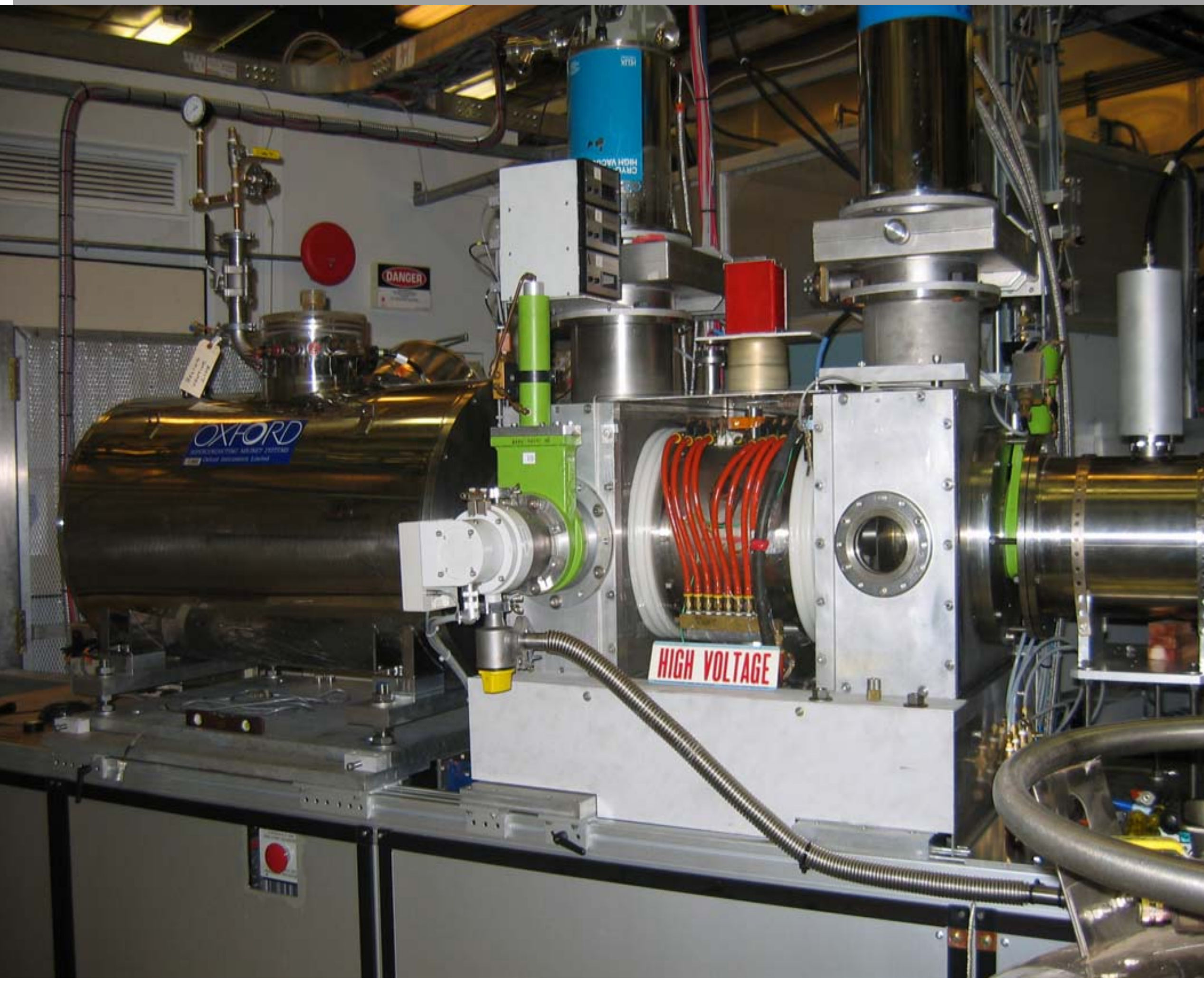
RHIC-AGS User Meeting, June 20, 2007

Polarization facilities at RHIC.

70% Polarization $\mathcal{L}_{max} = 1.6 \times 10^{32}\ s^{-1}cm^{-2}$ $50 < \sqrt{s} < 500$ GeV



Optically-Pumped Polarized H^- Ion Source (OPPIS) at RHIC.



A beam intensity greatly exceeds RHIC limit, which allowed strong beam collimation in the Booster, to reduce longitudinal and transverse beam emittances.

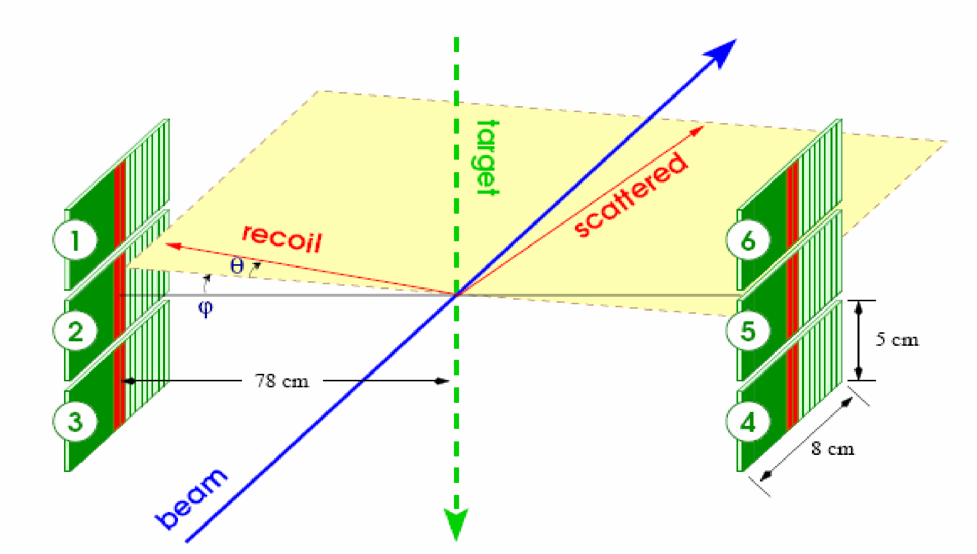
RHIC OPPIS produces reliably 0.5-1.0mA (maximum 1.6 mA) polarized H^- ion current.
Pulse duration 400 us.
Polarization at 200 MeV P = 85-90 %.

Beam intensity (ion/pulse) routine operation:

Source	- 10^{12} H^-/pulse
Linac (200MeV)	- $5{\cdot}10^{11}$
Booster	- $2{\cdot}10^{11}$, 50% - scraping.
AGS	- $1.7{\cdot}10^{11}$
RHIC	- $1.4{\cdot}10^{11}$ (p/bunch).

H-jet polarimeter. Atomic Beam Source.

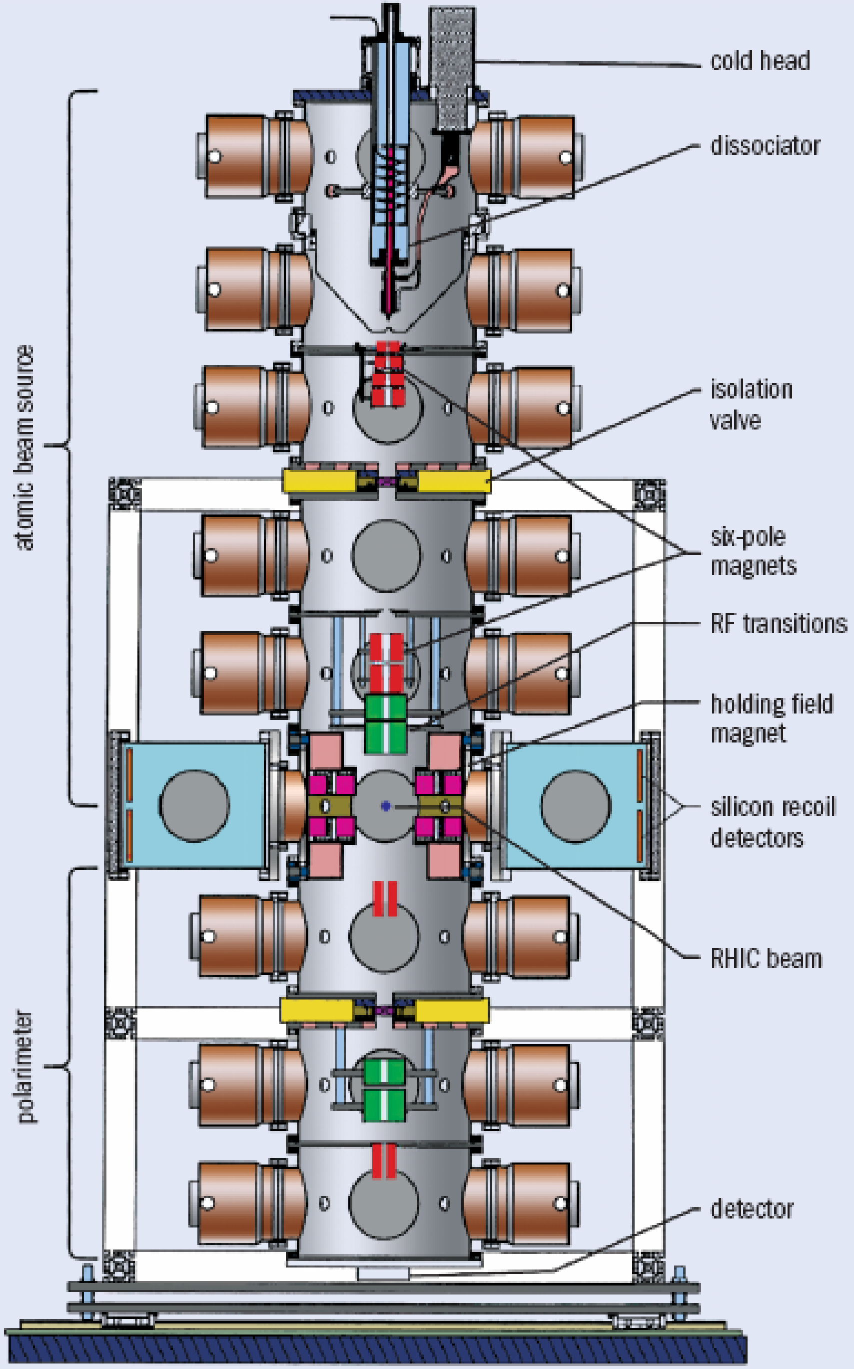
Atomic beam intensity- 12 $\cdot 10^{16}$ atoms/s
H-jet thickness -1.5$\cdot$ 10^{12} atoms/cm^2
Atomic beam polarization-96%



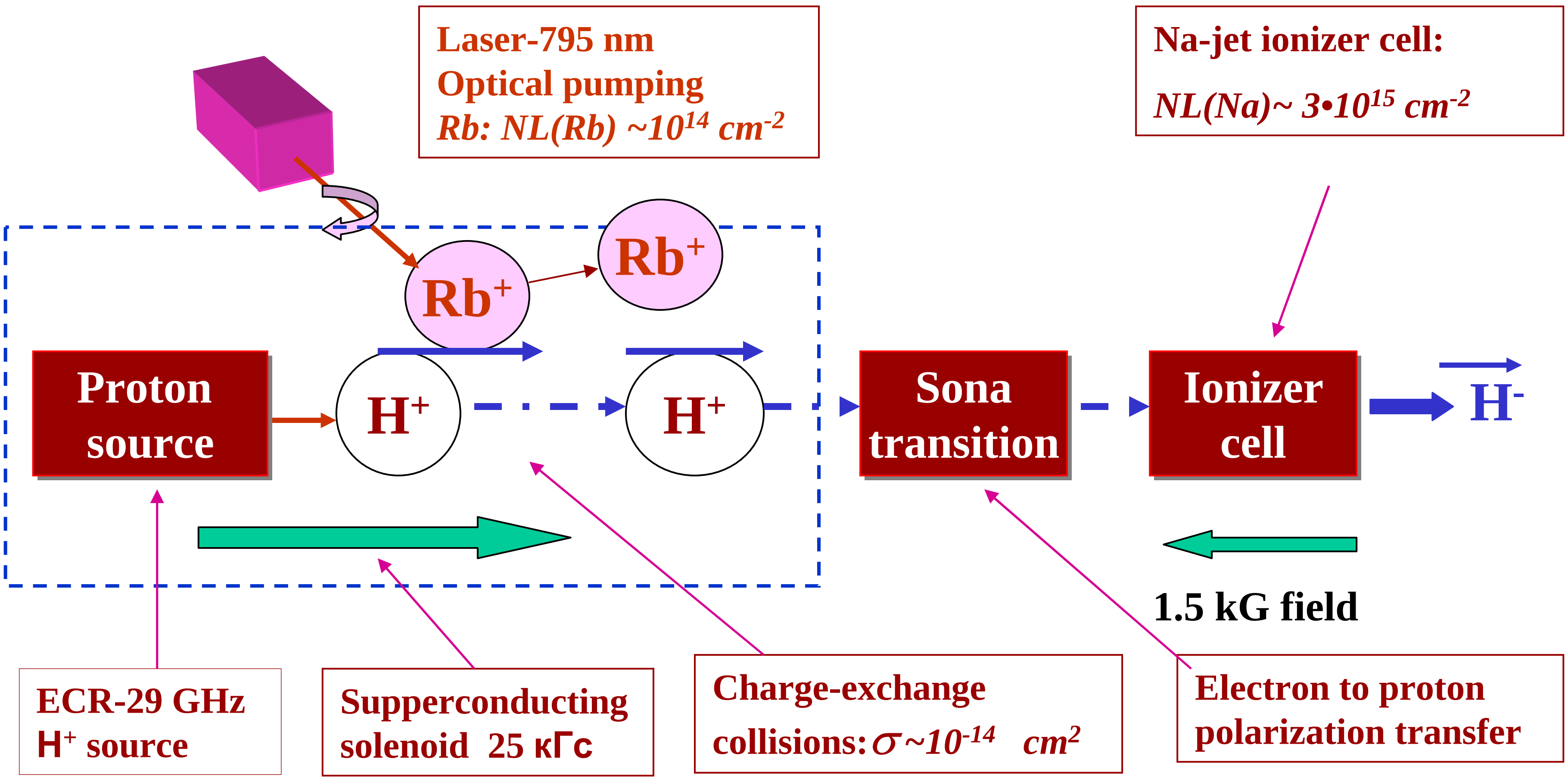
$$A_N^{beam}(t) = -A_N^{target}(t)$$

for elastic scattering!

$$P_{beam} = P_{target} \cdot \varepsilon_N^{beam} / \varepsilon_N^{target}$$



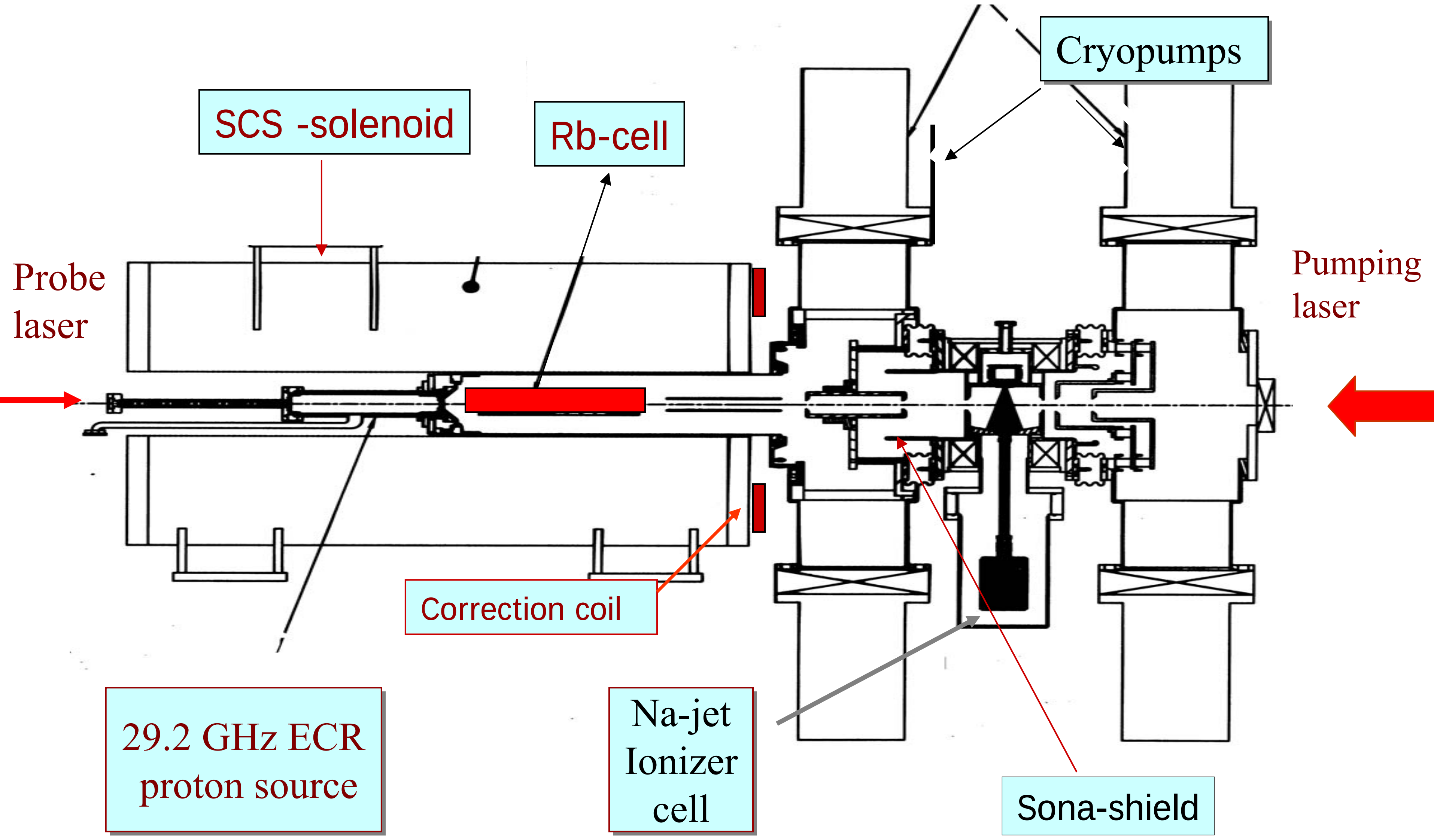
SPIN -TRANSFER POLARIZATION IN PROTON-Rb COLLISIONS.



Laser beam is a primary source of angular momentum:

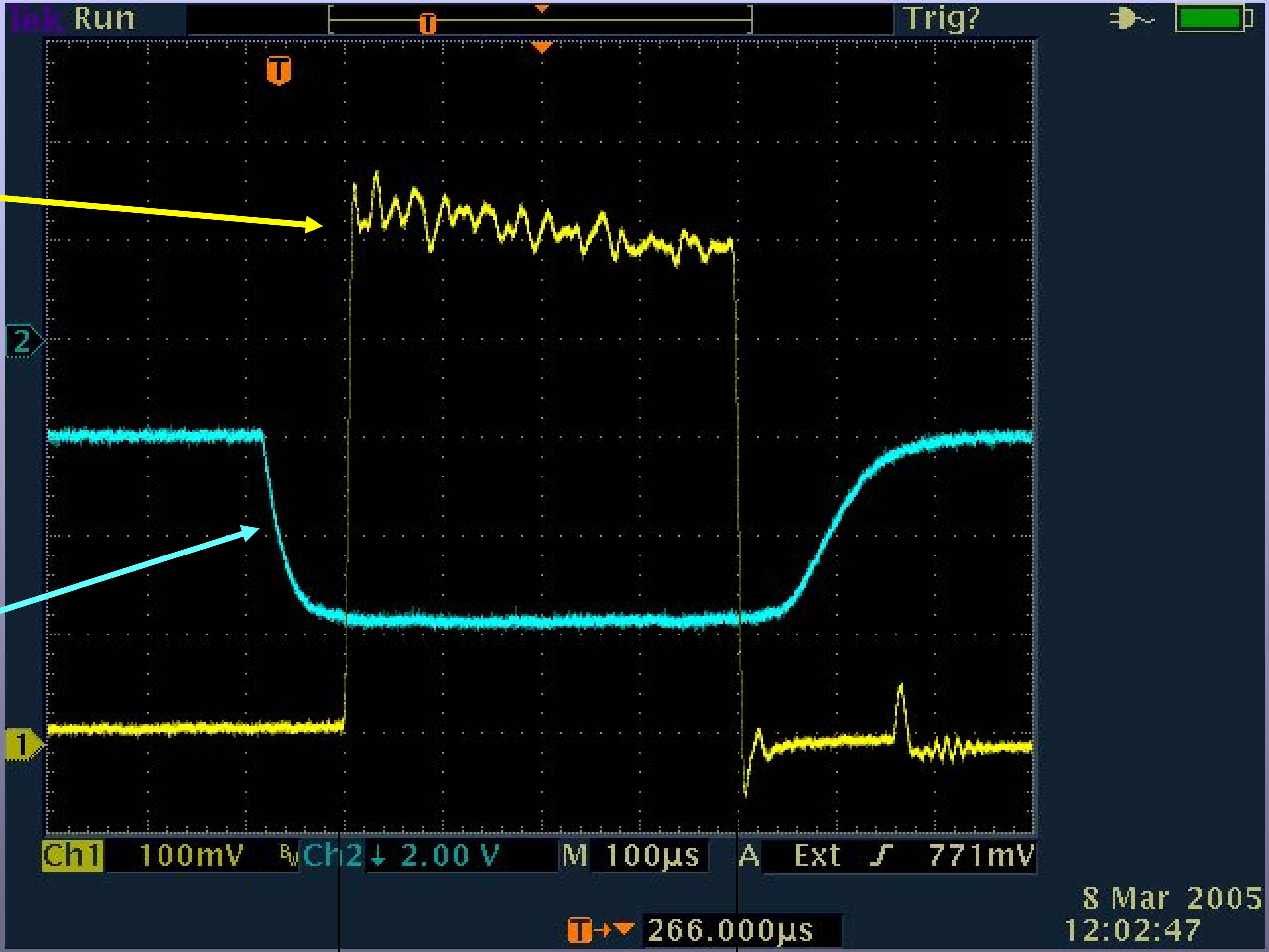
10 W (795 nm) $\Rightarrow$ $4 \cdot 10^{19}$ hν/sec $\Rightarrow$ 2 A, $\vec{H}^0$ equivalent intensity.

SCHEMATIC LAYOUT OF THE RHIC OPPIS.



Polarized H⁻ ion current pulse out of 200 MeV linac.

500 uA cuurent
At 200 MeV.
85-hole ECR
Source for the
maximum
polarization.

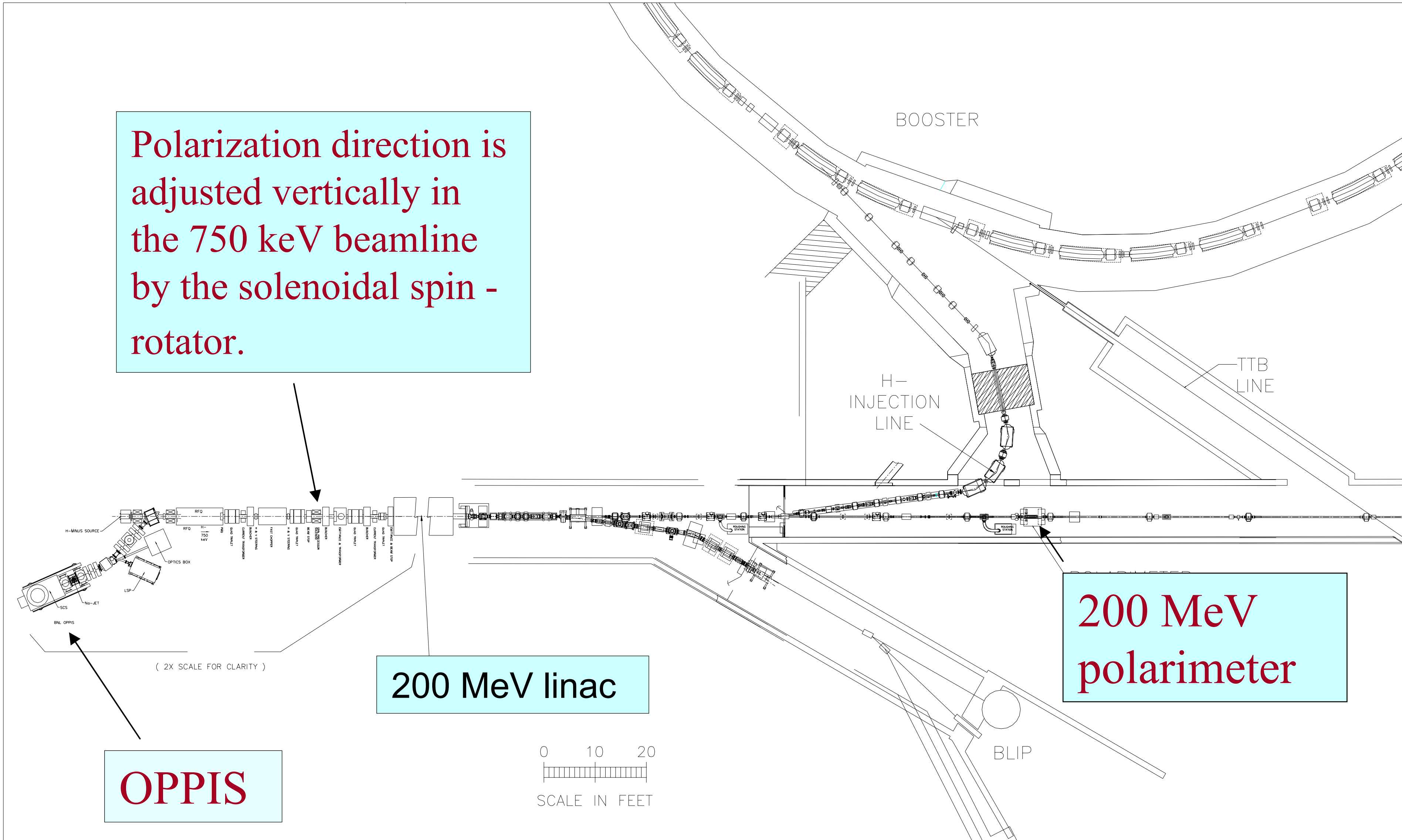


Faradey rotation
polarization sinal.

400 uS

$12 \cdot 10^{11}$ -polarized
H^- /pulse.

Polarized injector, 200 MeV linac and injection lines.



OPPIS operation in Run-2006

- BNL OPPIS reliably delivered polarized H^- ion beam (P= 82-86%) in the 2006 run for the RHIC spin program.
- A beam intensity greatly exceeds RHIC bunch intensity limit, which allowed strong beam collimation in the Booster, to reduce longitudinal and transverse beam emittances.

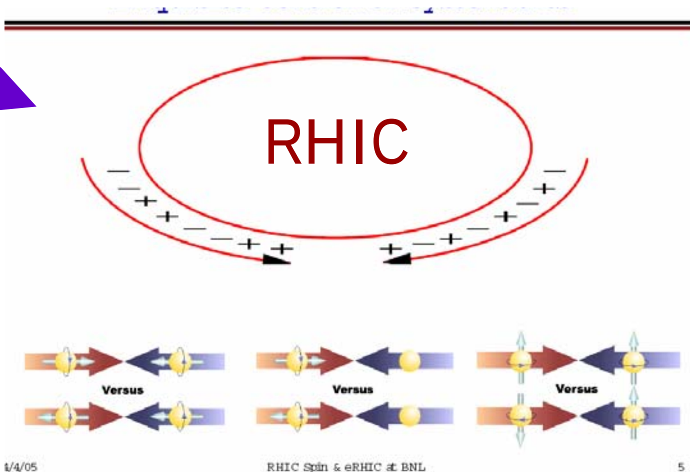
Polarized beams in RHIC.

OPPIS — $10 \cdot 10^{11}$ (maximum $40 \cdot 10^{11}$) polarized H^- /pulse, P =85%

LINAC — $5 \cdot 10^{11}$ polarized H^- /pulse at 200 MeV, P=85%

Booster — $2 \cdot 10^{11}$ polarized protons /pulse at 2.3 GeV

AGS — 1.5-1.7 p/bunch, P ~65-70%



Maximum RHIC bunch intensity ~1.5 10^{11} p/bunch

Polarization -65%

Polarization measurement in 200 MeV polarimeter.

ANALYSIS

	Pol	(%)	dPol	mean_lu	dmean	mean_ru	dmean	mean_ld	dmean	mean_rd	dmean	good_pts
All......:	86.42	+/-	5.47	99.47	8.45	32.79	6.09	31.74	5.45	114.53	9.38	19
4SigmaCut:	86.42	+/-	5.47	99.47	8.45	32.79	6.09	31.74	5.45	114.53	9.38	19
3SigmaCut:	86.42	+/-	5.47	99.47	8.45	32.79	6.09	31.74	5.45	114.53	9.38	19
2SigmaCut:	86.70	+/-	5.60	98.12	7.33	32.24	5.62	31.59	5.76	114.71	9.90	17
1SigmaCut:	86.02	+/-	4.46	97.60	6.88	31.20	4.27	32.40	3.91	111.80	3.63	5

86.7%

32	121.0	30.0	1335.0	0.0	0.9293	2.0	0.0
33	36.0	115.0	0.0	1335.0		1.0	1.0
34	107.0	28.0	1335.0	0.0	0.9078	1.0	1.0
35	25.0	120.0	0.0	1336.0		0	
36	90.0	43.0	1335.0	0.0	0.8357	1	
37	33.0	111.0	0.0	1335.0		0	
38	104.0	45.0	1336.0	0.0	0.7581	1	
39	29.0	148.0	0.0	1335.0		0	

200 μA× 400 μs pulse at 200 MeV

~ $4.8 \cdot 10^{11}$ H^-/pulse

AVERAGING INTERVAL: 5 | HISTOGRAM: GET HISTOGRAM | ANALYSIS: ANALYZE

86.4%

Left arm events (+,-):	1922 - 32	608 - 5	96.1 - 1.6	32.0 - 0.2632
Right arm events(+,-):	624 - 1	2183 - 7	31.2 - 0.05	114.9 - 0.3684

POLARIZATION (P,dP): 0.8643 0.01874 AVE POL(LAST 100) (P,dP): 0.865 0.08891

RIGHT(SINGLE) POLARIZATION (P,dP): -0.8958 0.02207

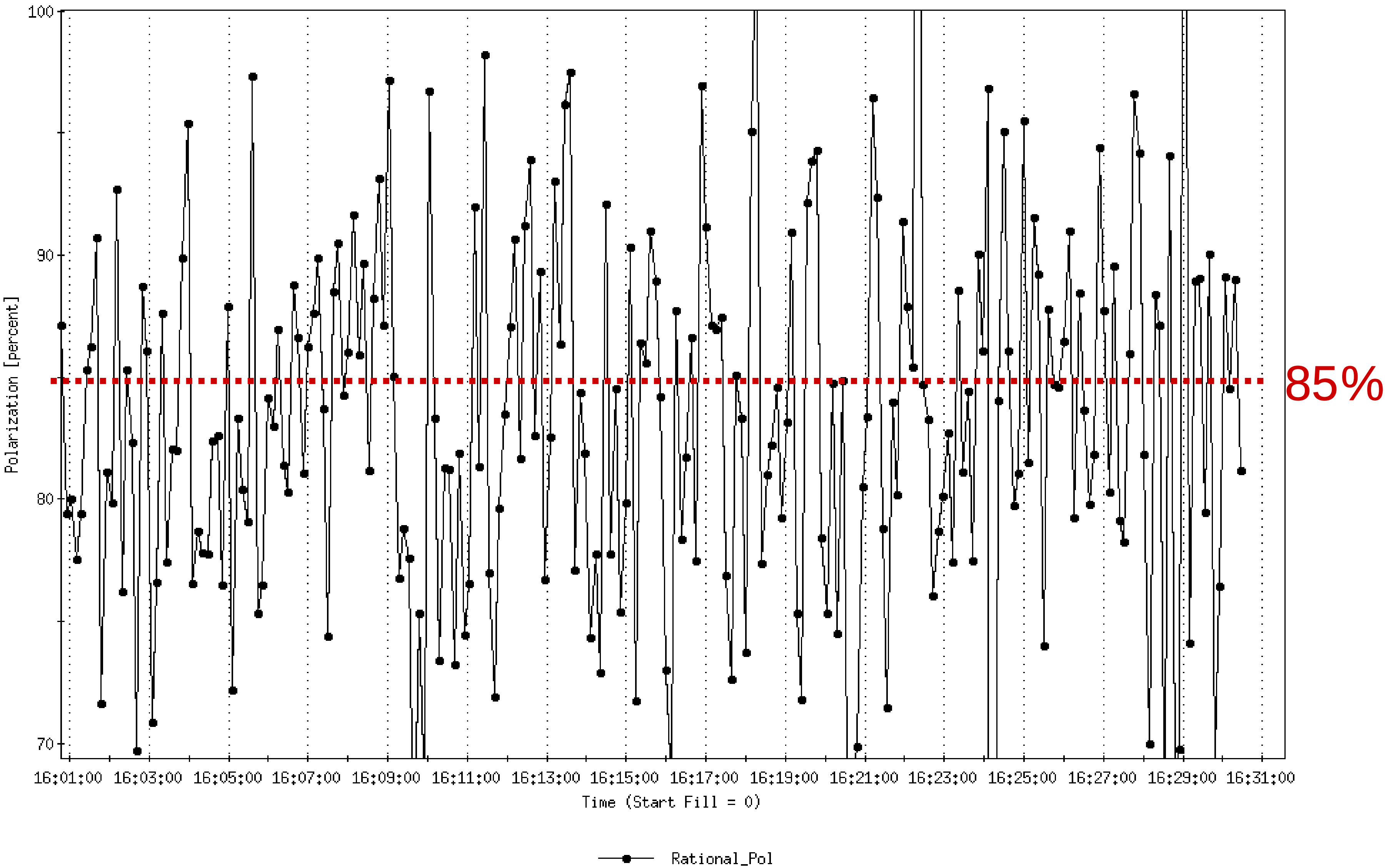
LEFT(SINGLE) POLARIZATION (P,dP): 0.8377 0.01316

POLARIZATION (L/R) (P,dP): 0.8326 0.0003489

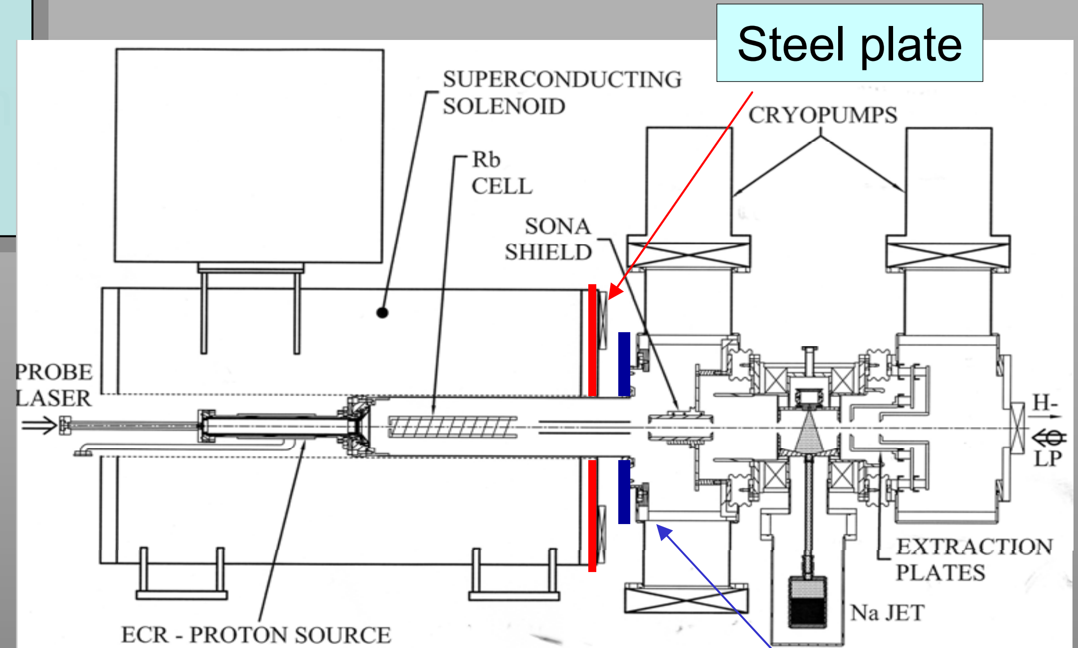
RESTART

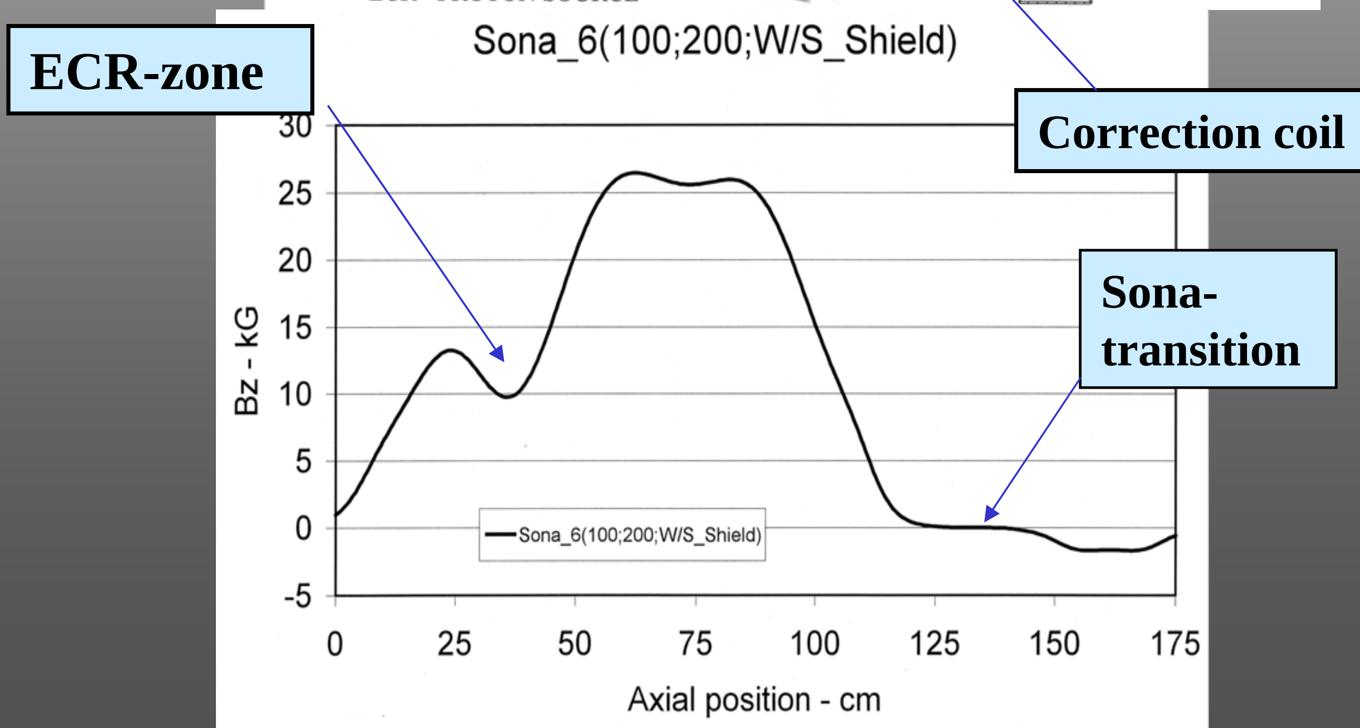
Thu Mar 02 12:28:38 PM EST 2006

Polarization measurements in 200 MeV polarimeter.



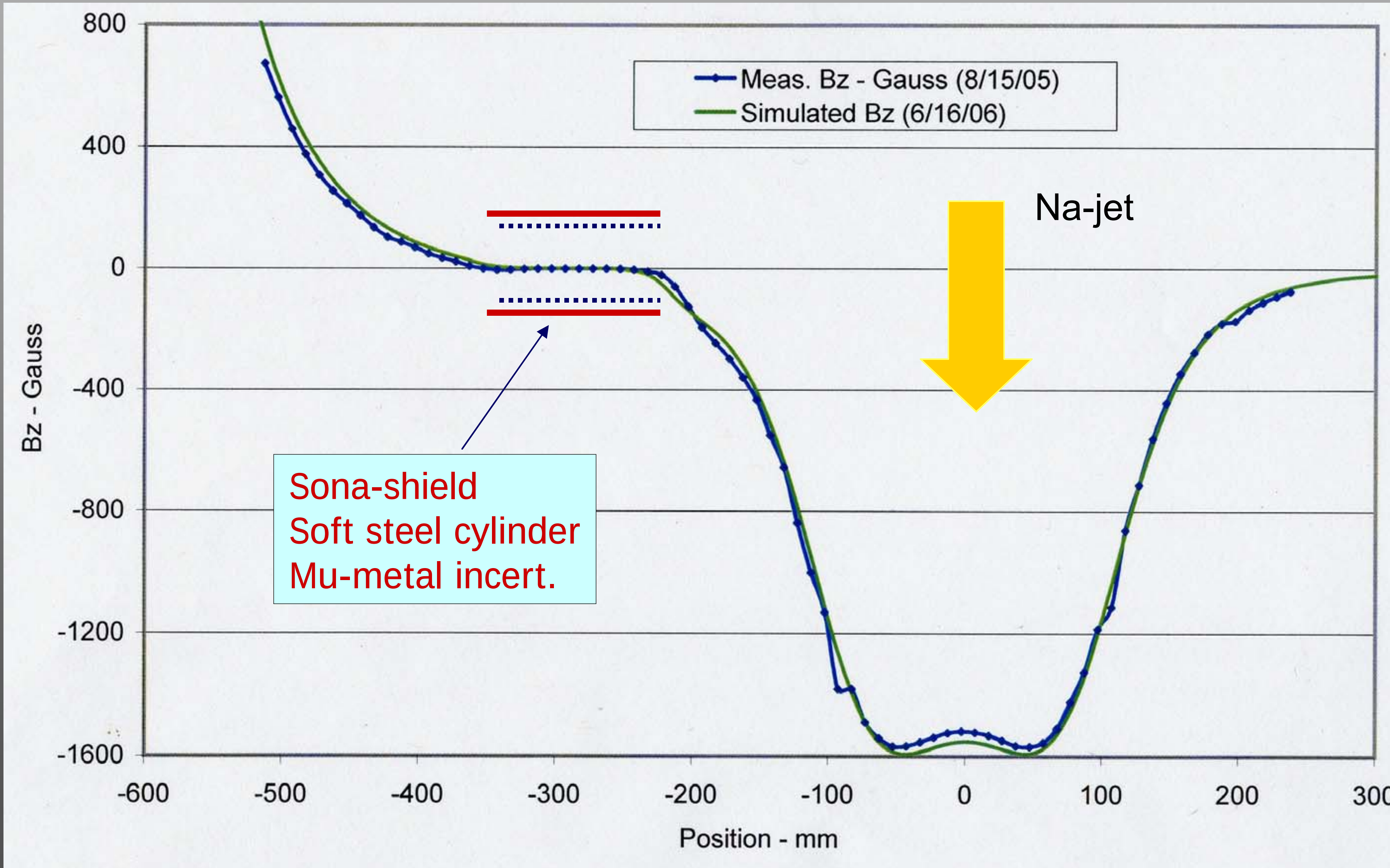
SONA-TRANSITION. Polarization transfer from electrons to protons.



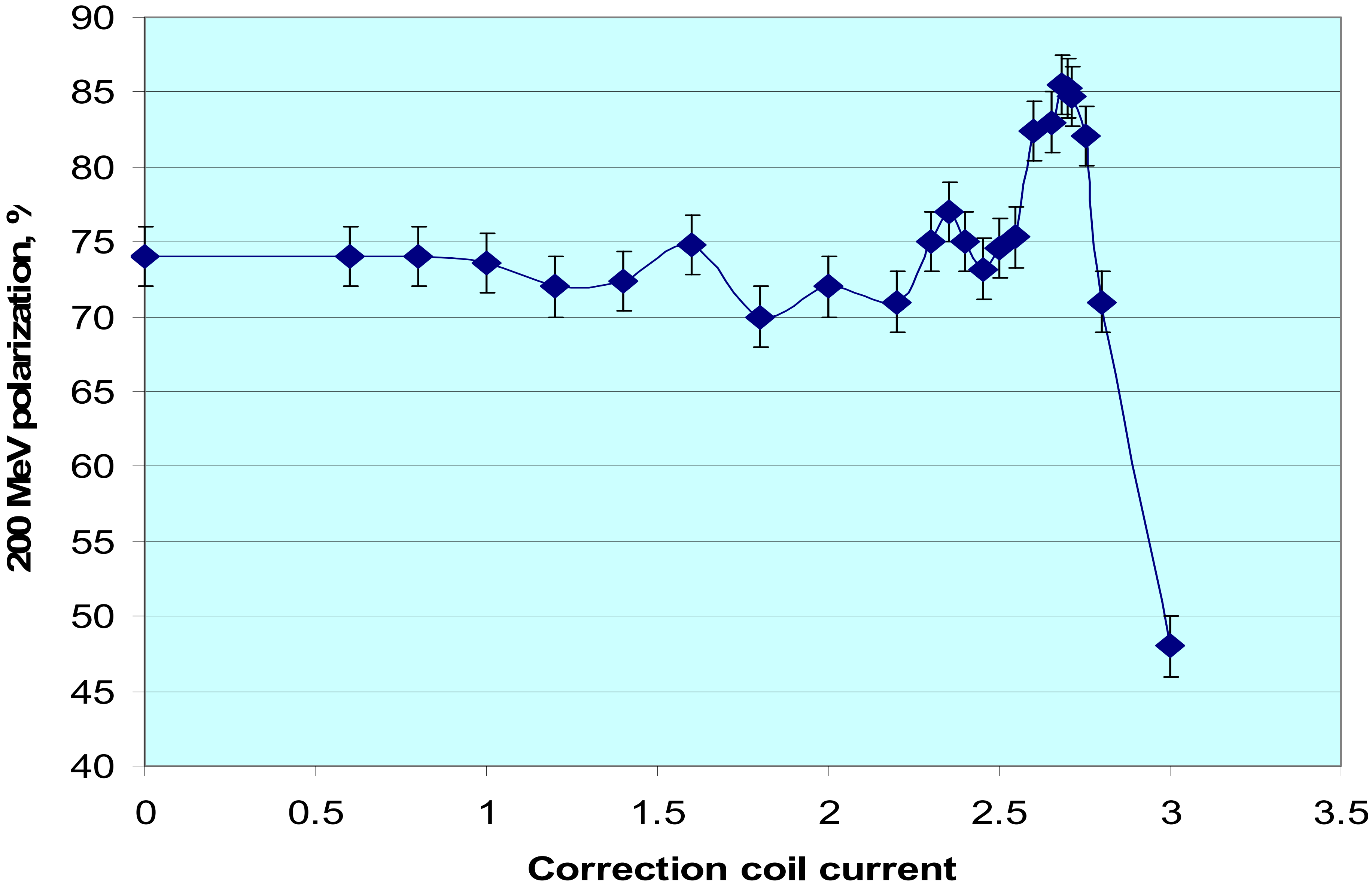


Bz-field component in the Sona-transition region.

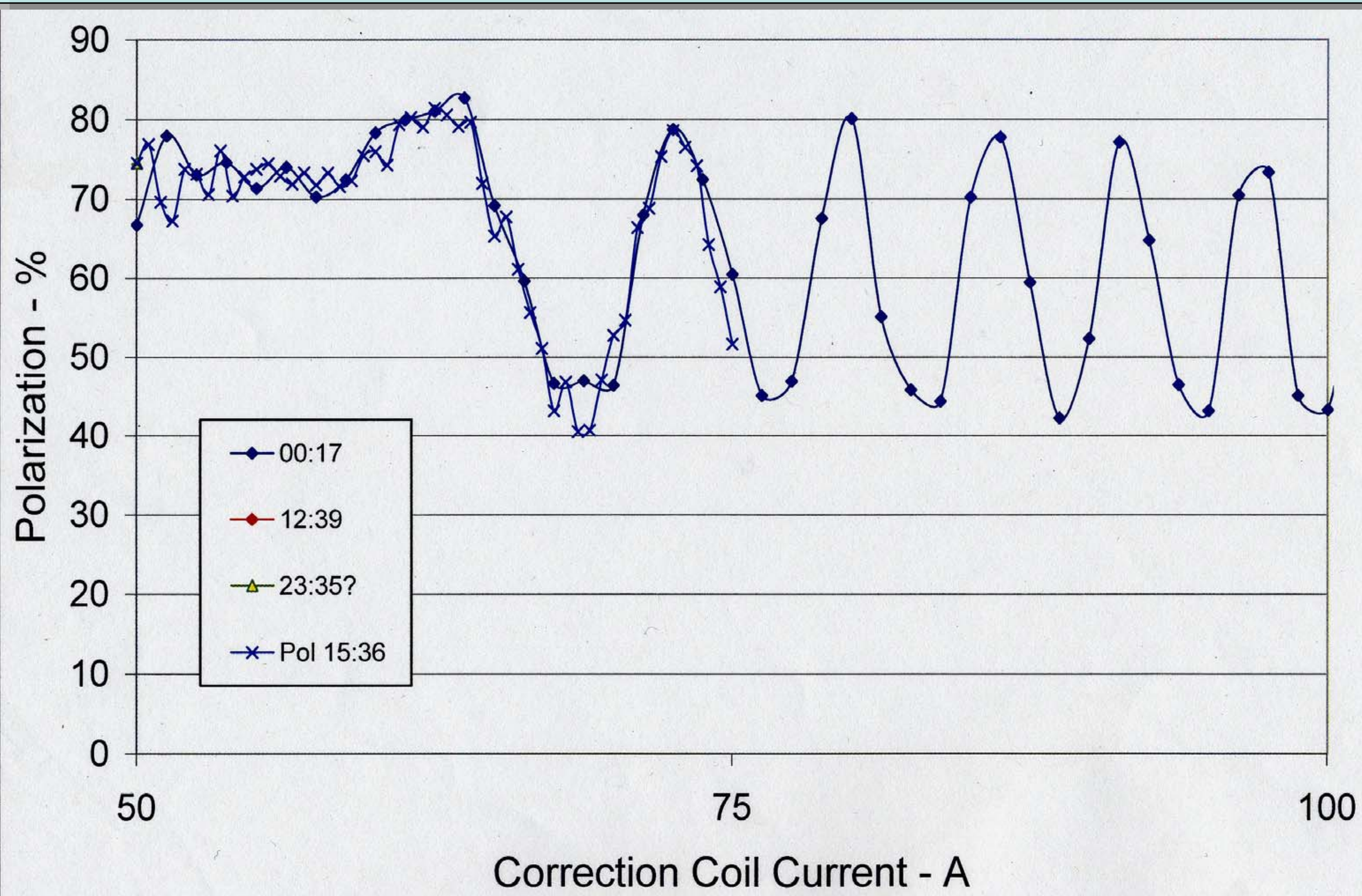
Multiple charge-exchange: $H^0 \longrightarrow H^- \longrightarrow H^0 \longrightarrow H^-$



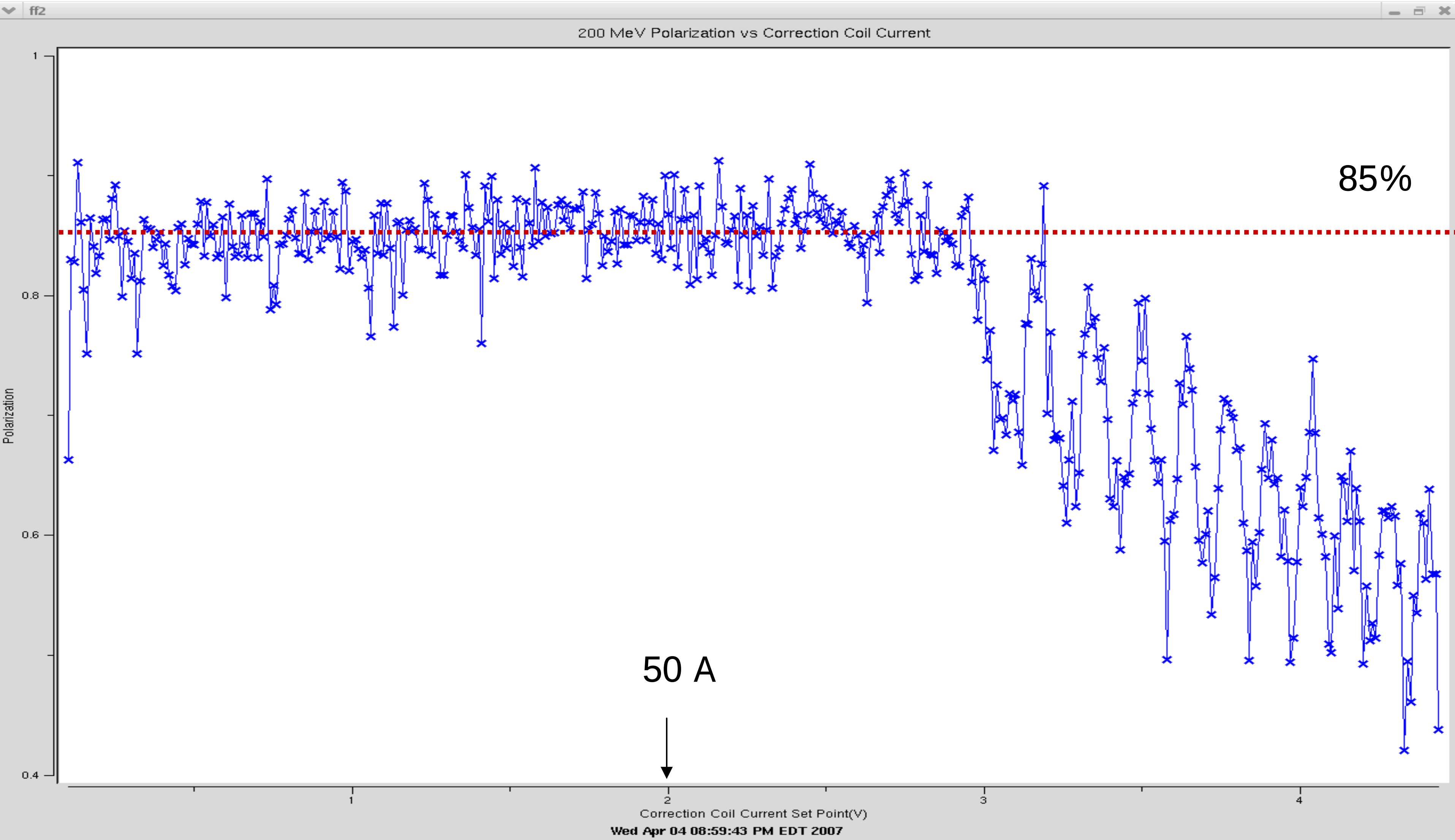
Polarization vs Correction Coil current with a new Sona-shield.



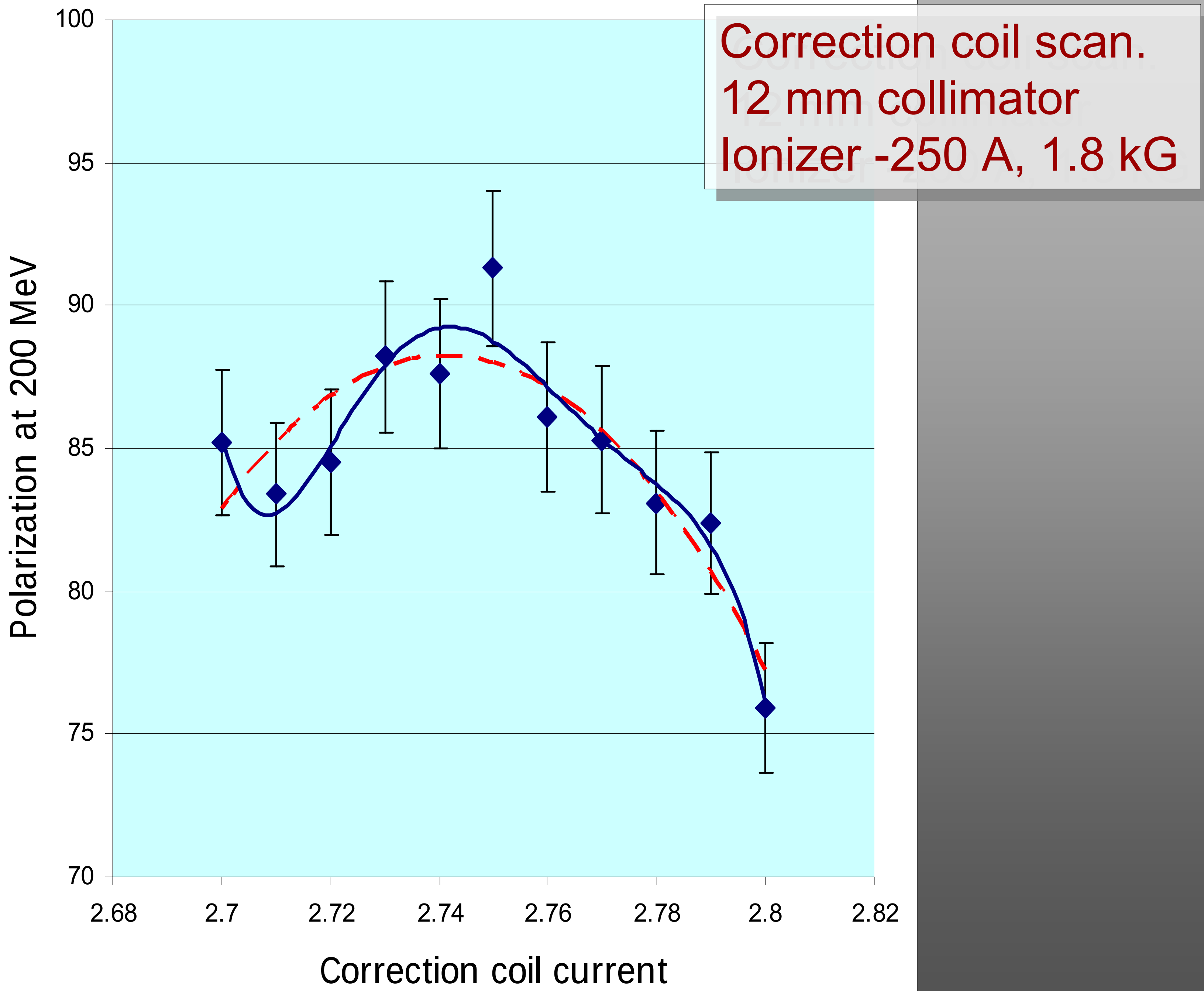
Polarization oscillations vs Correction Coil current.



Polarization oscillation in Sona-transition



Polarization at 200 MeV vs. Correction Coil current


Correction coil scan.
12 mm collimator
Ionizer -250 A, 1.8 kG
Polarization at 200 MeV
100
95
90
85
80
75
70
2.68
2.7
2.72
2.74
2.76
2.78
2.8
2.82
Correction coil current

Polarization vs. ionizer solenoid current with the 12mm collimator.

Maximum polarization from the correction coil scans, collim. -12 mm.

160 A ↔1.16 kG, 81.6% (95.9%)

200 A ↔1.45 kG, 84.9% (97.0%)

250 A ↔1.81 kG , 88.1% (98.1%)

Theoretical limit

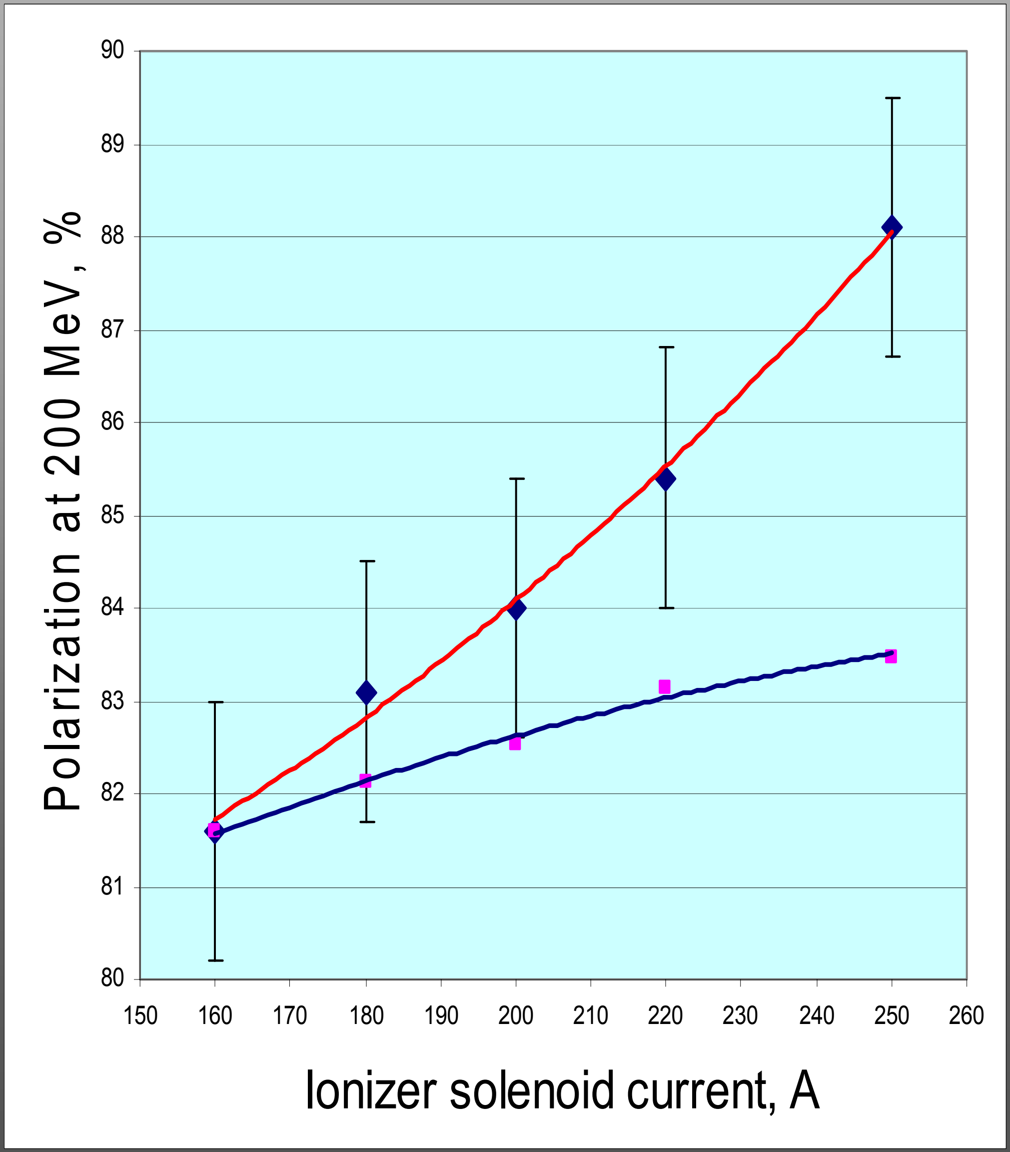
23 mm collimator.

200 A ↔1.45 kG, 82.5% (97.0%)

250 A ↔1.81 kG , 84.5% (98.1%)

A new ionizer solenoid:

250 A ↔1.98 kG , 90.0% (98.4%)



200 MeV POLARIMETER (12 degree-accidental) u5v12 -- FOR POLARIZATION STUDIES)

STATUS: RUNNING

PROCESSING

START | STOP | SAVE | CLEAR | EXIT

READING

PULSE	LEFT	RIGHT	CLK-	CLK+	POL.	ACC_L	ACC_R	(L/R)u	(R/L)d
36	42.0	135.0	0.0	1335.0	0.744684	0.0	1.0	0.311111	0.428571
37	97.0	25.0	1340.0	0.0		2.0	0.0	0.311111	0.257732
38	31.0	142.0	0.0	1335.0	0.98921	0.0	0.0	0.21831	0.257732
39	1.0	0.0	1340.0	0.0		0.0	0.0	0.21831	0.0
40	27.0	124.0	0.0	1335.0	1.6129	0.0	3.0	0.217742	0.0
41	97.0	42.0	1339.0	0.0		1.0	0.0	0.217742	0.43299
42	37.0	144.0	0.0	1336.0	0.800808	0.0	1.0	0.256944	0.43299
43	105.0	34.0	1339.0	0.0		1.0	0.0	0.256944	0.32381
44	35.0	131.0	0.0	1336.0	0.870422	0.0	3.0	0.267176	0.32381
45	125.0	37.0	1340.0	0.0		1.0	0.0	0.267176	0.296
46	29.0	150.0	0.0	1335.0	0.986482	0.0	1.0	0.193333	0.296
47	108.0	31.0	1339.0	0.0		1.0	0.0	0.193333	0.287037
48	35.0	131.0	0.0	1335.0	0.906534	0.0	2.0	0.267176	0.287037
49	106.0	33.0	1340.0	0.0		0.0	0.0	0.267176	0.311321
50	24.0	131.0	0.0	1336.0	0.991028	0.0	0.0	0.183206	0.311321

AVERAGING INTERVAL 5

HISTOGRAM GET HISTOGRAM

ANALYSIS 91.2+/-1.5%

ALPHA

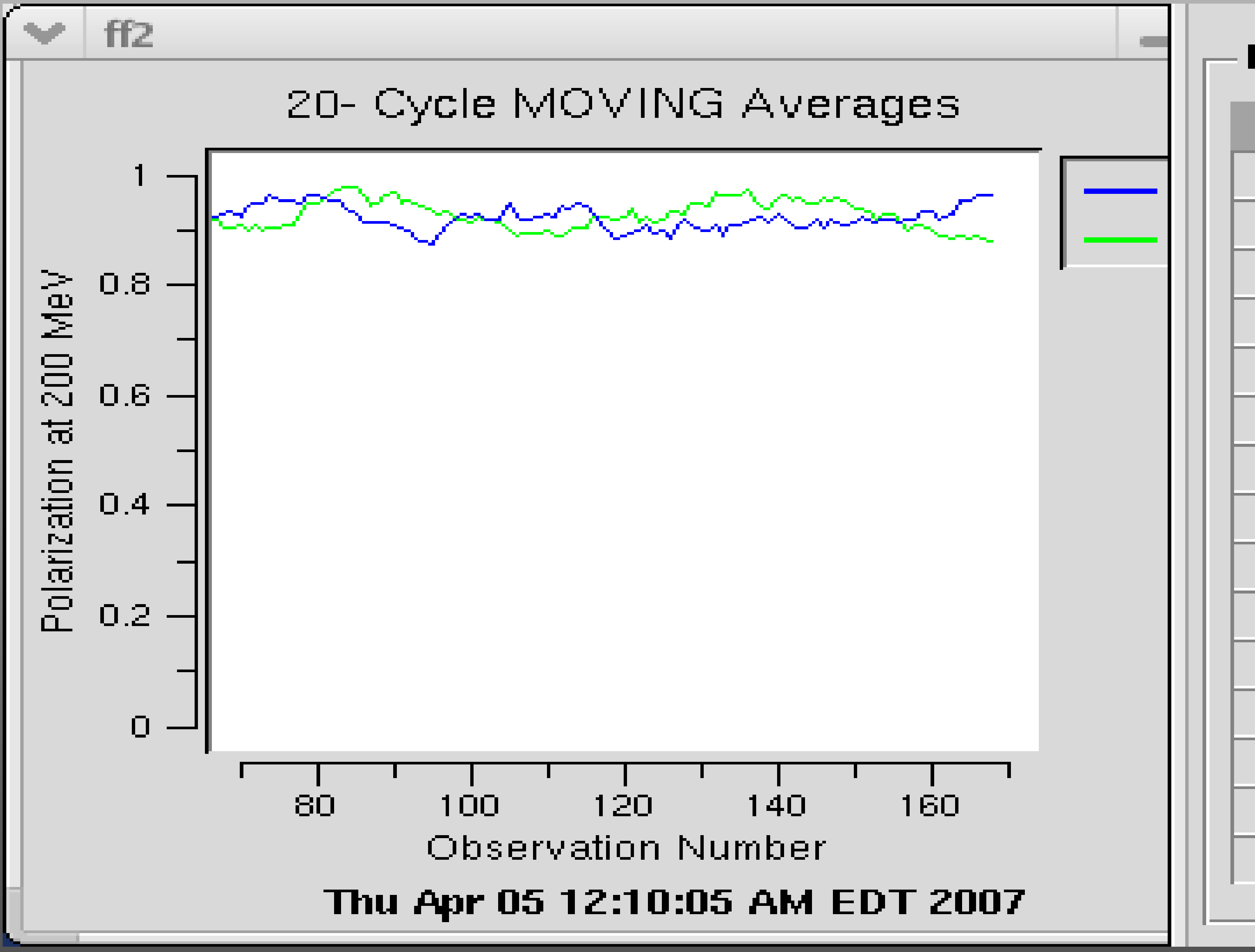
Left arm events (+,-):	762.0 - 3.0	2483.0 - 20.0	30.48 - 0.12	99.32 - 0.8
Right arm events(+,-):	3473.0 - 25.0	863.0 - 1.0	138.92 - 1.0	34.52 - 0.04

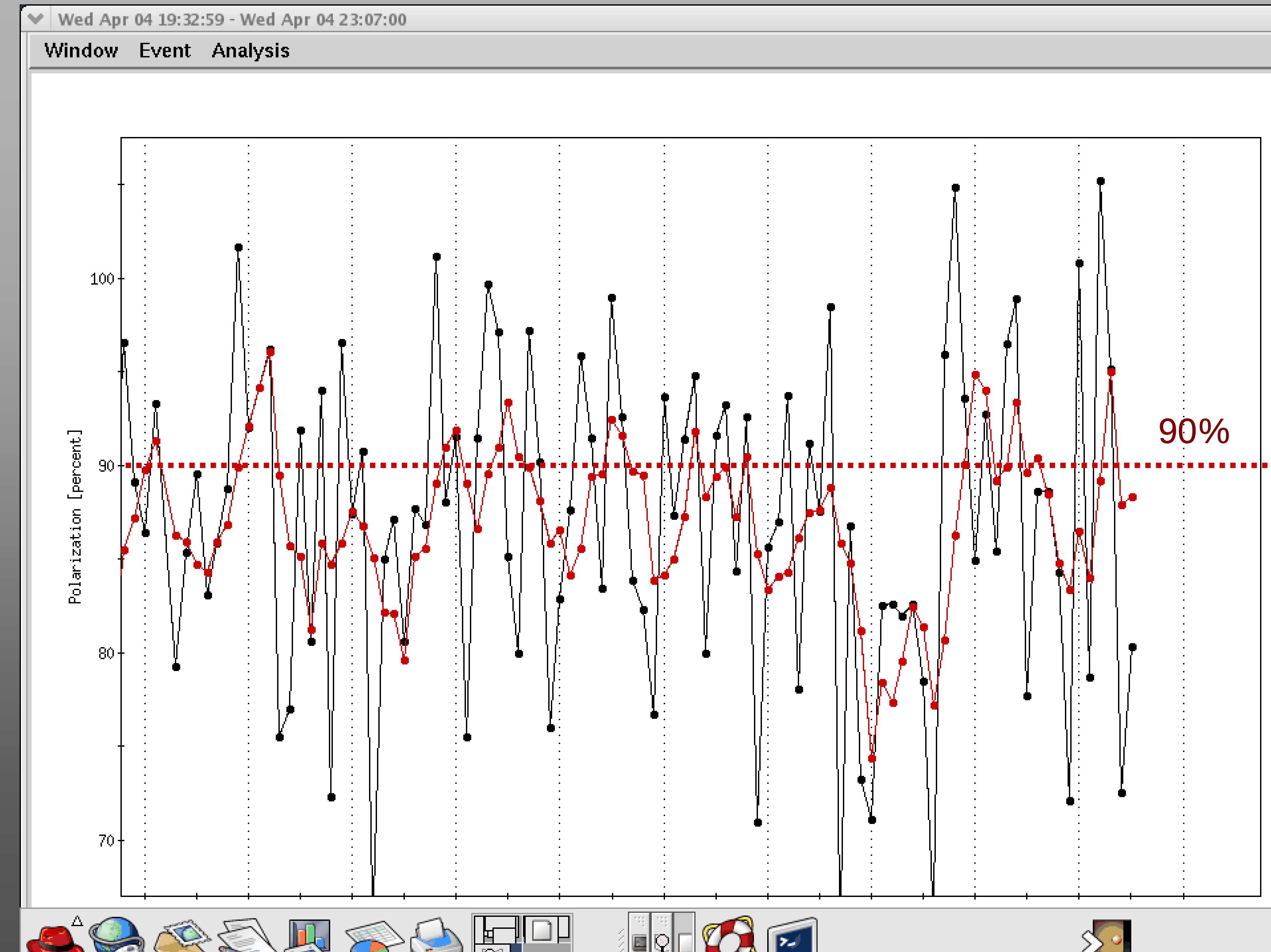
POLARIZATION (P,dP): 0.912069 0.0154519 AVE POL(LAST 20 Cycles) (P,dP): 0.992385 0.178412

RIGHT(SINGLE) POLARIZATION (P,dP): 0.970867 0.00857756 UP POLARIZATION: 0.951075

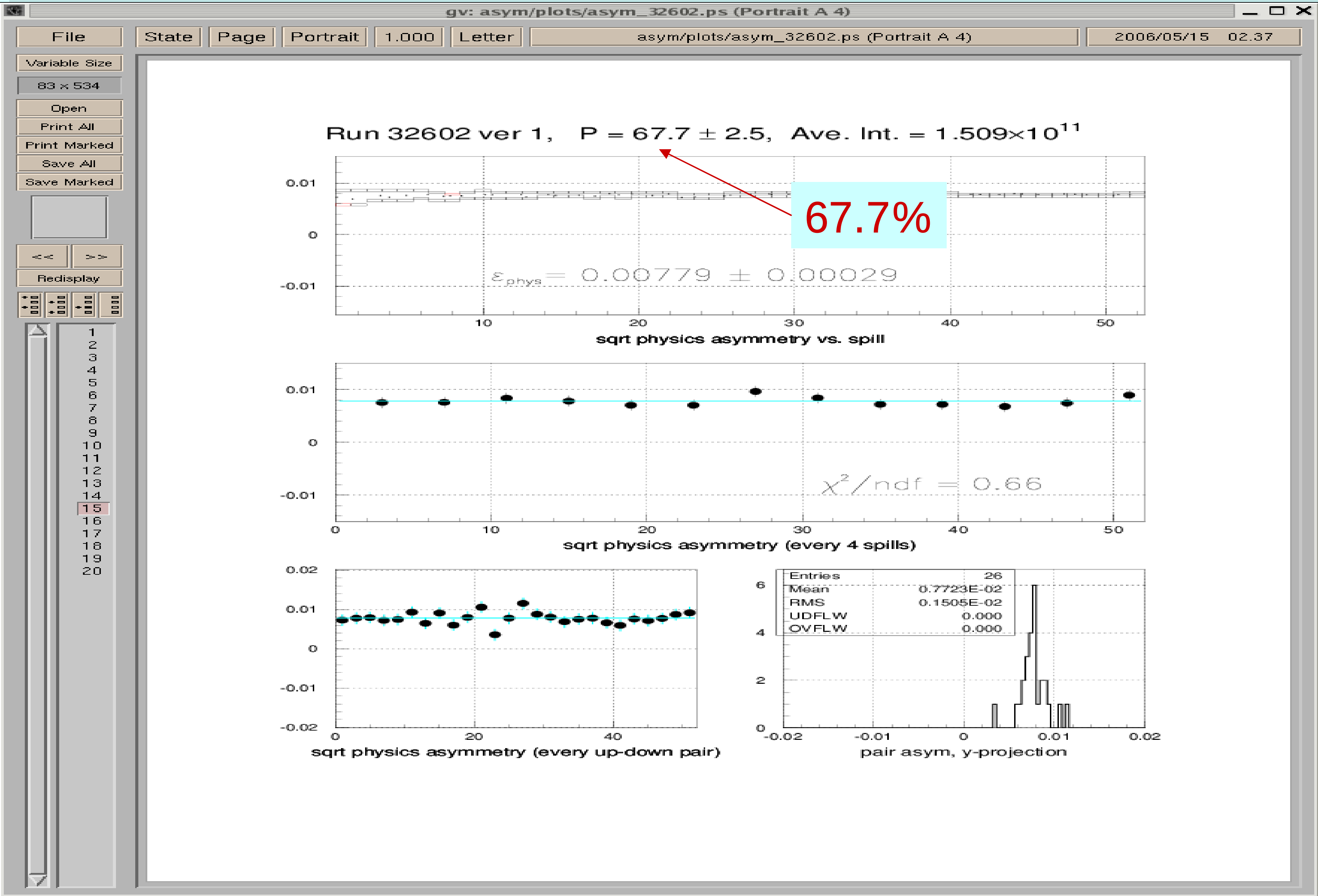
LEFT(SINGLE) POLARIZATION (P,dP): 0.85541 0.0207752 DOWN POLARIZATION: -0.877242

POLARIZATION (L/R) (P,dP): 0.856941 0.000236641


ff2
20- Cycle MOVING Averages
Polarization at 200 MeV
1
0.8
0.6
0.4
0.2
0
80
100
120
140
160
Observation Number
Thu Apr 05 12:10:05 AM EDT 2007

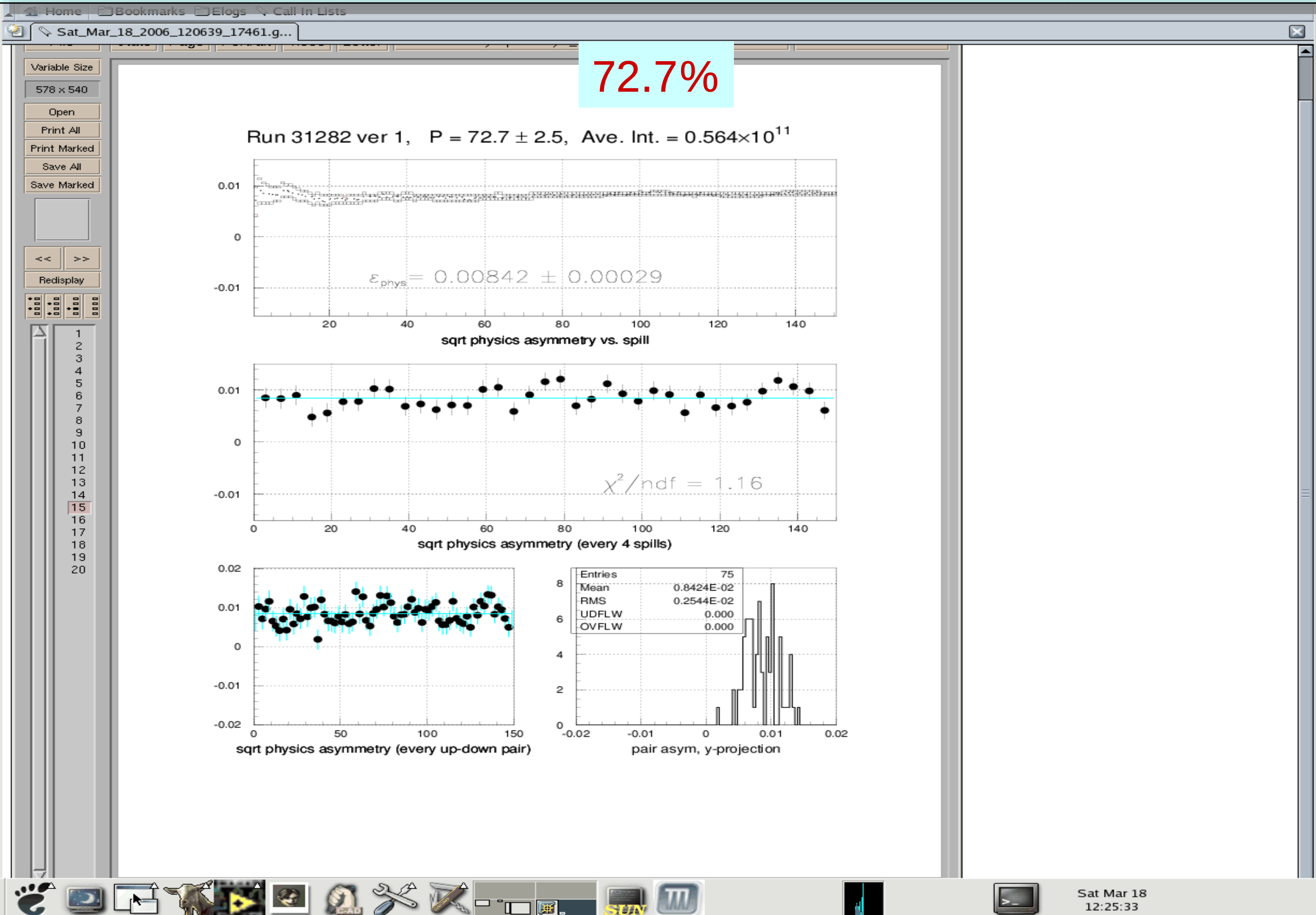

Wed Apr 04 19:32:59 - Wed Apr 04 23:07:00
Window
Event
Analysis
Polarization [percent]
100
90
80
70
90%

Polarization measurement in AGS, Run 06.

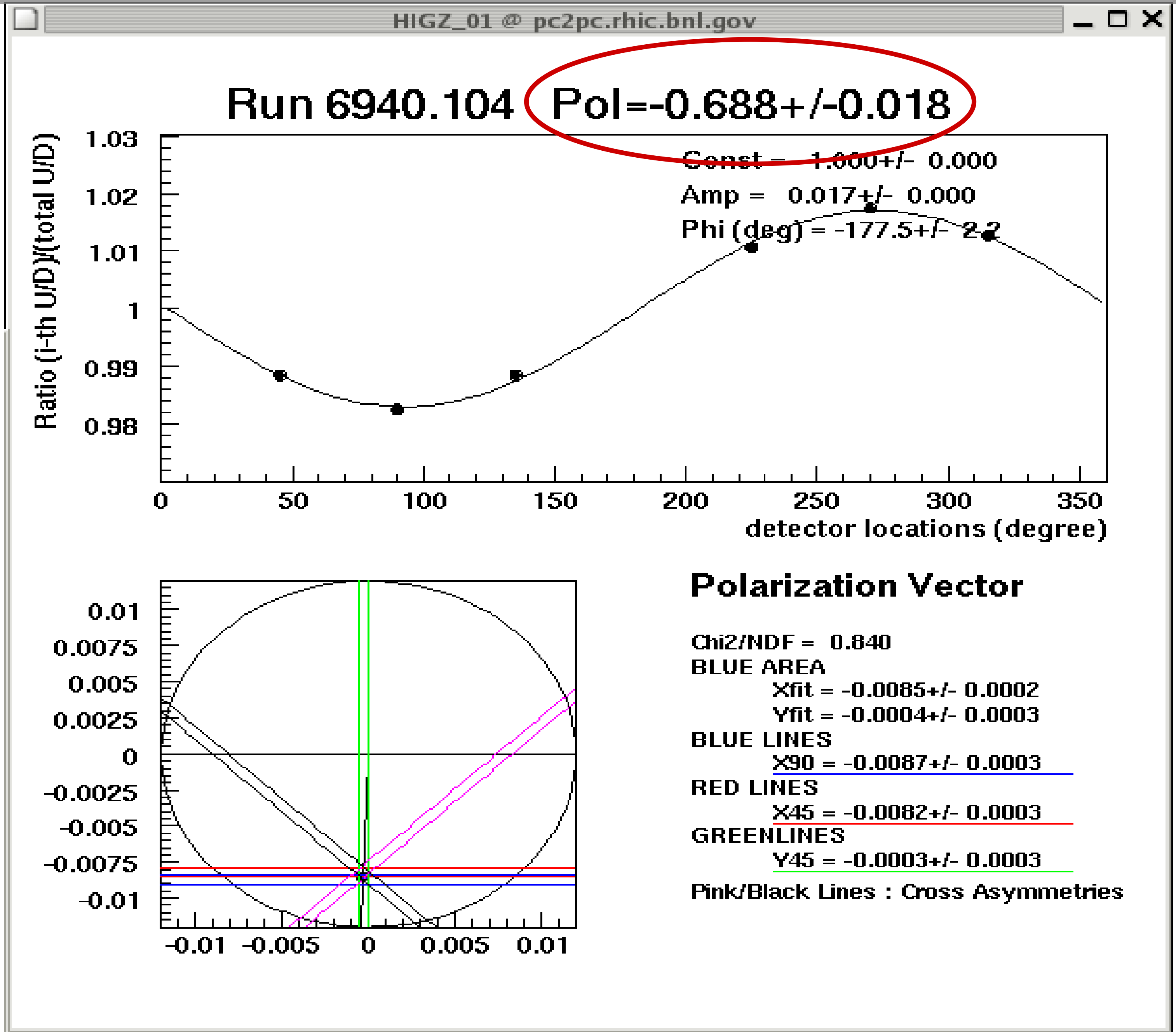


Polarization measurement in AGS at 24 GeV, Run 06.

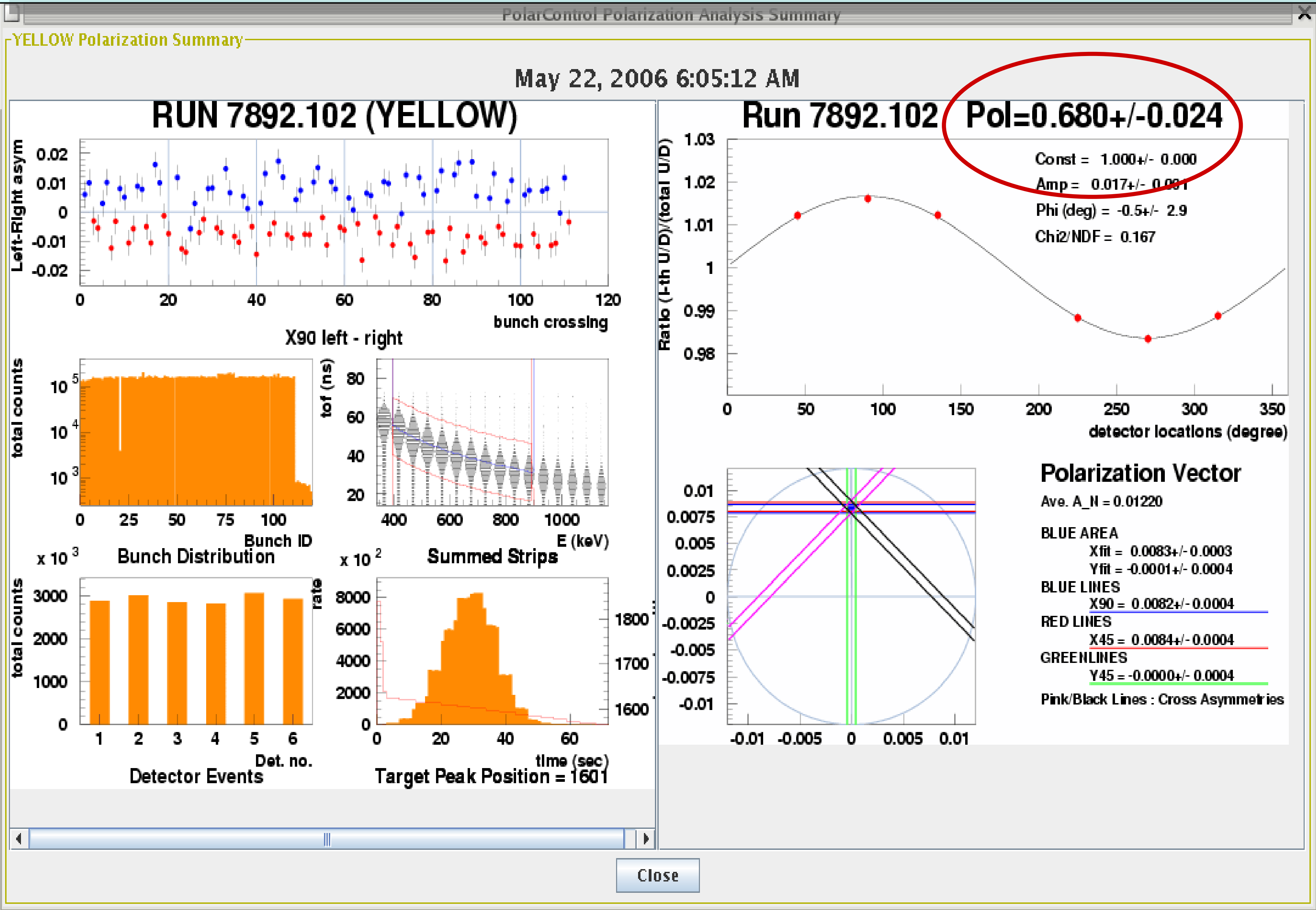
72.7%



Polarization at 24 GeV in RHIC with reduced beam intensity.



Polarization measurements in RHIC at 100 GeV.



Feasibility studies of new polarization techniques for electron, H^- ion and $^3He^{++}$ ion beams.

A.Zelenski, J.Alessi, E.Beebe, A.Kponou, M.Okamura, A.Pikin, J.Ritter, BNL
R.Milner, F.Simon MIT Bates, C.O'Connel,CALTEC
V.Zubets, (INR, Moscow), V. Davidenko, BINP Novosibirsk

”Optical pumping” polarization technique.

The RHIC operational polarized source setup will be used in these studies.

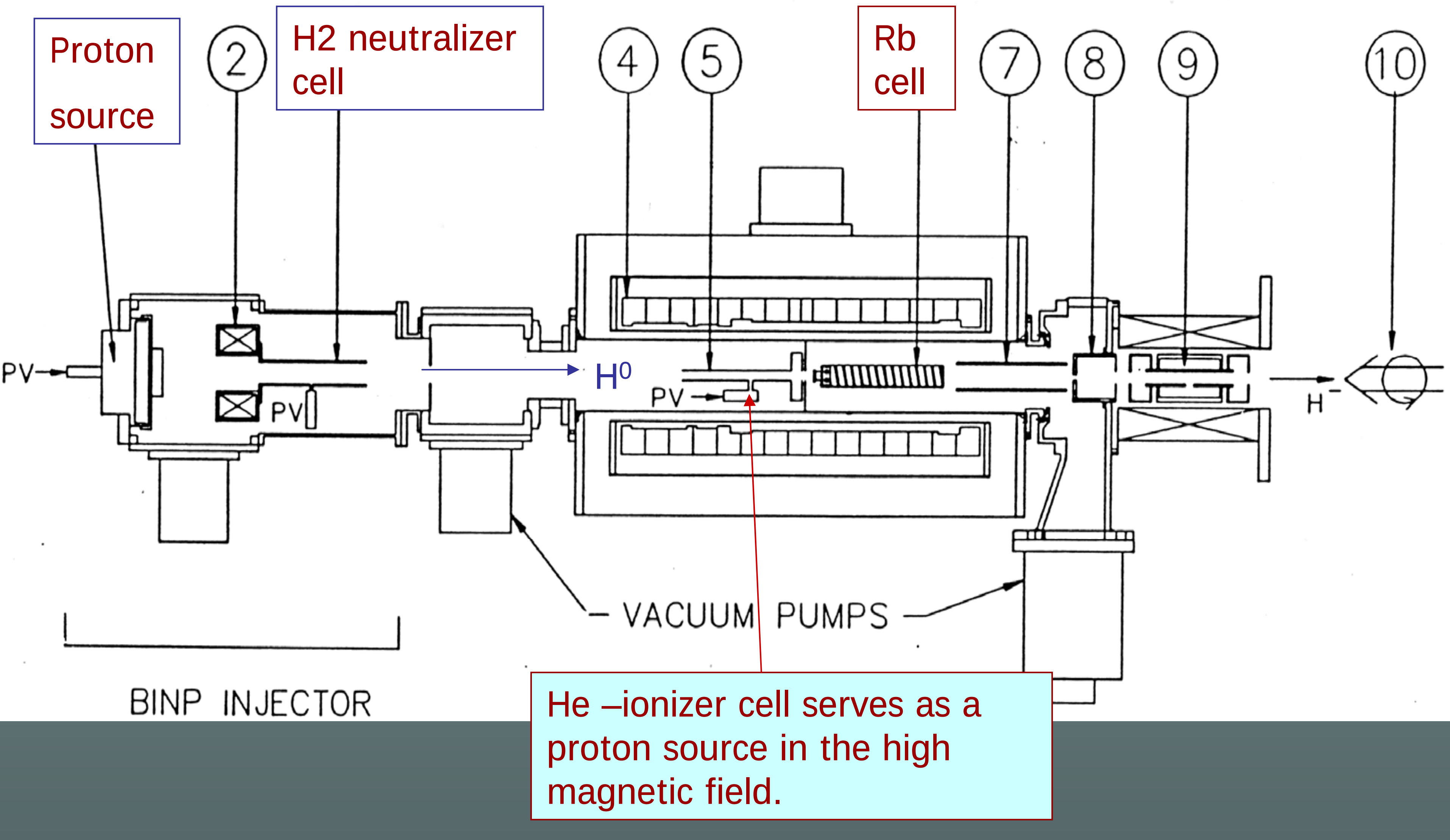
A new generation of polarized electron, H^- and $^3He^{++}$ ion sources will provide polarized beams for RHICII and eRHIC spin physics.

OPPIS upgrade with the atomic H injector.

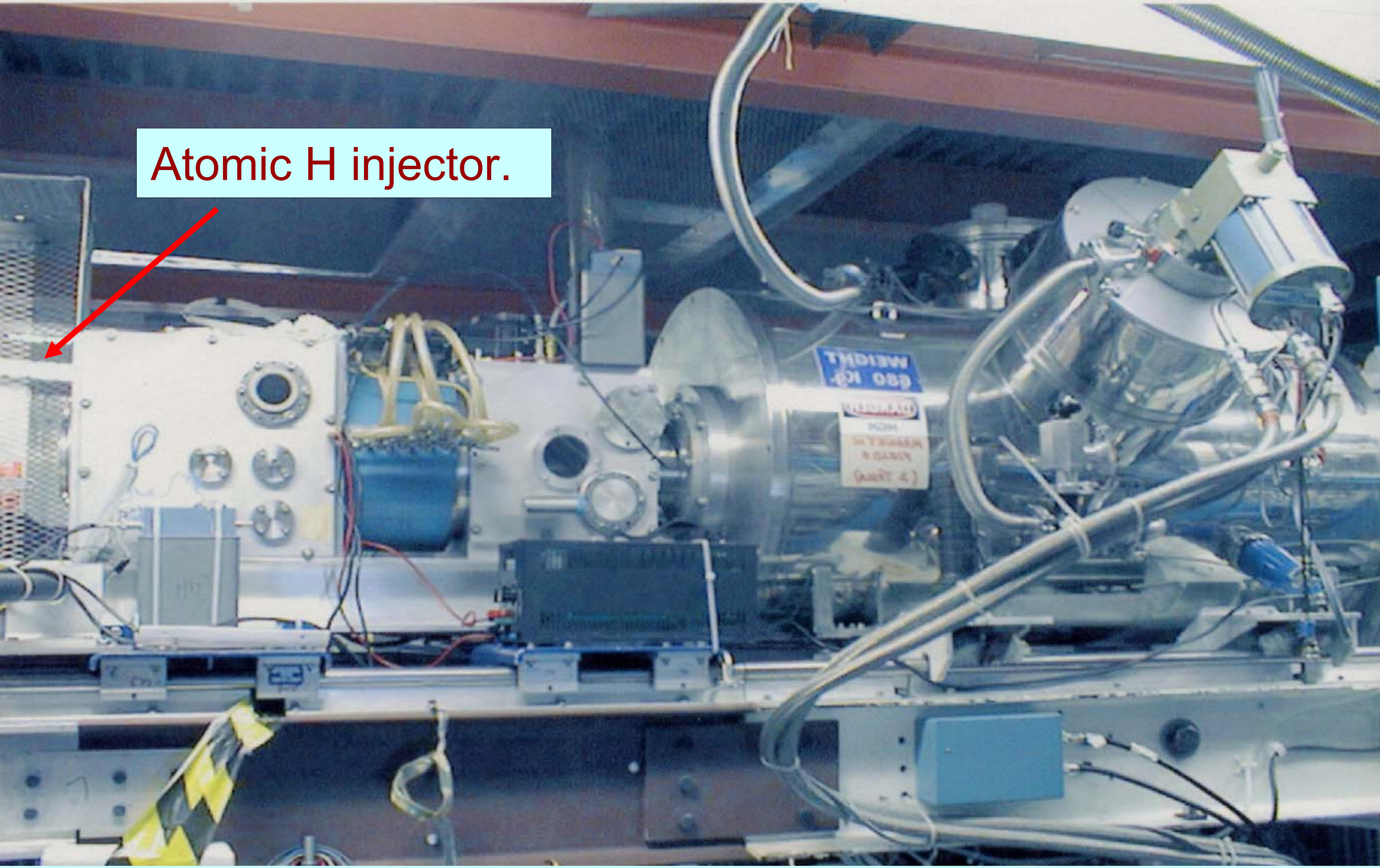
- Atomic H injector produces an order of magnitude higher brightness beams than ECR proton source.
- A 5-10 mA H^- ion current can be easily obtained with the smaller, about 12 mm in diameter beam. This reduces most of possible polarization losses and produce smaller emittance polarized beam.
- Neutralization in the residual gas is much smaller too.
- All these factors combined will increase polarization to over 90%.

Major purchase will be a new superconducting solenoid ~$150 k.

Pulsed OPPIS layout.

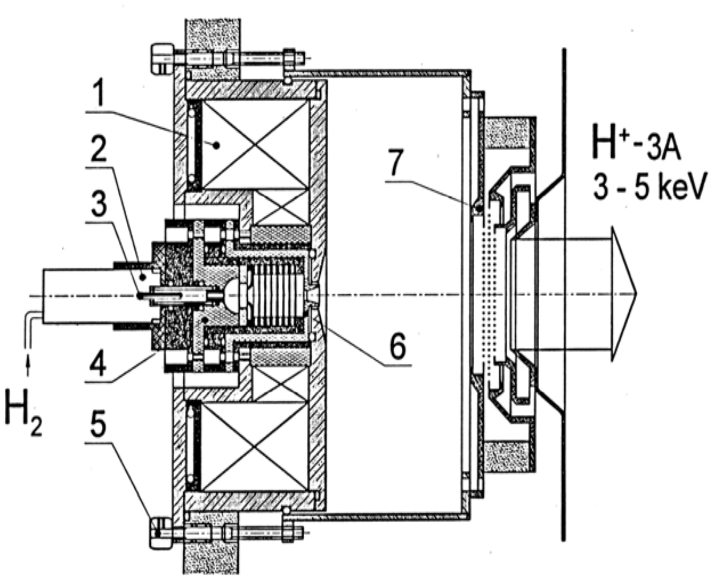


Pulsed OPPIS at TRIUMF, 1999.

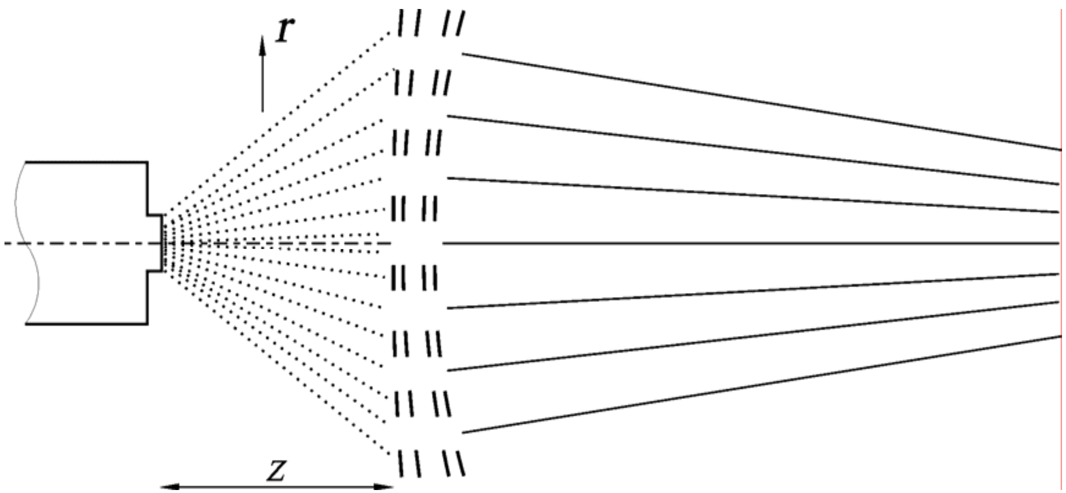


A polarized H- ion current of a 10 mA (peak) was obtained in 1999!.

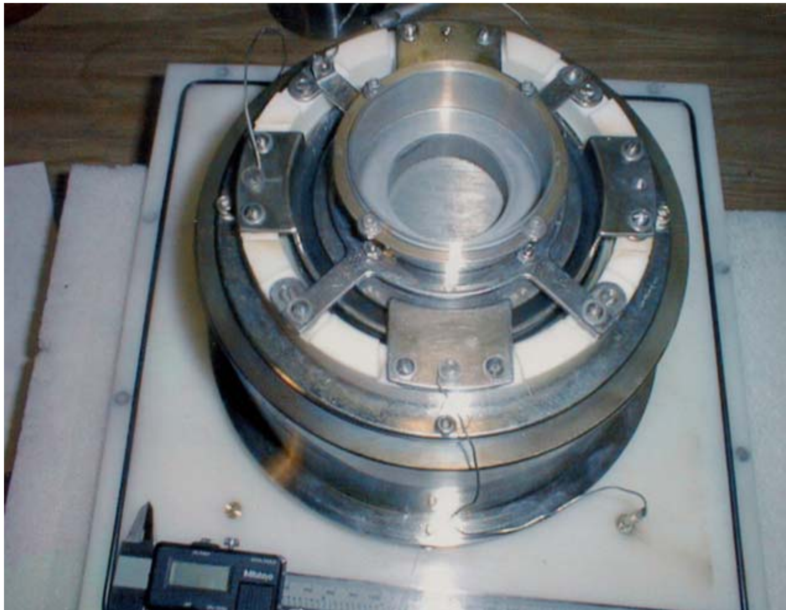
Proton “cannon” of the atomic H injector.



Ion Optical System with “geometrical focusing”.



The source produced 3 A ! pulsed proton current at 5.0 keV.



~20-50 mA H^- current. P=75-80%

~10 mA , P ≥ 90%.

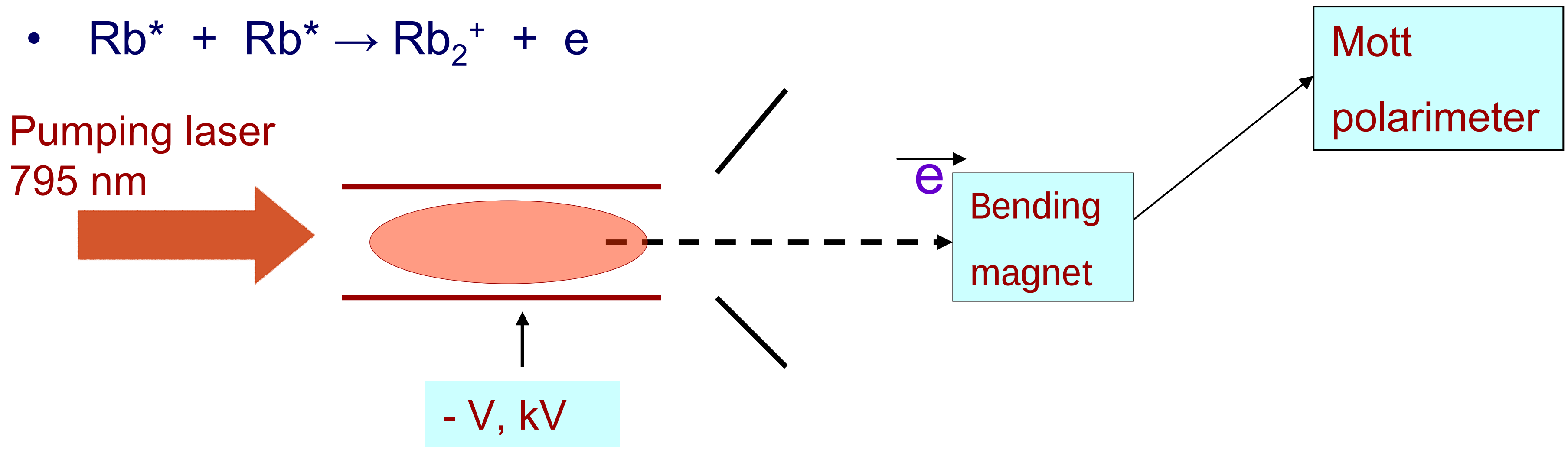
~ 300 mA unpolarized H^- ion current.

Polarized electron production in the process of associative ionization.

A strong ionization was discovered in the process of optical pumping of high density sodium vapor by high power laser resonant light. This effect was later understood as an associative ionization of alkali metal atoms in collisions of two atoms in exited states. Nearly 100% alkali vapor ionization can be produced in a vapor cell of a 10^{13} atoms/cm3 or higher vapor density.

Electron excitation is produced by optical pumping in the magnetic field, **therefore electrons which are produced in the process of ionization must be polarized.**

- Rb ionization potential is 4.18 eV
- Optical pumping at $5S_{1/2} \rightarrow 5P_{1/2}$ at 795 nm (1.55 eV)
- $Rb^* + Rb^* \rightarrow Rb_2^+ + e$



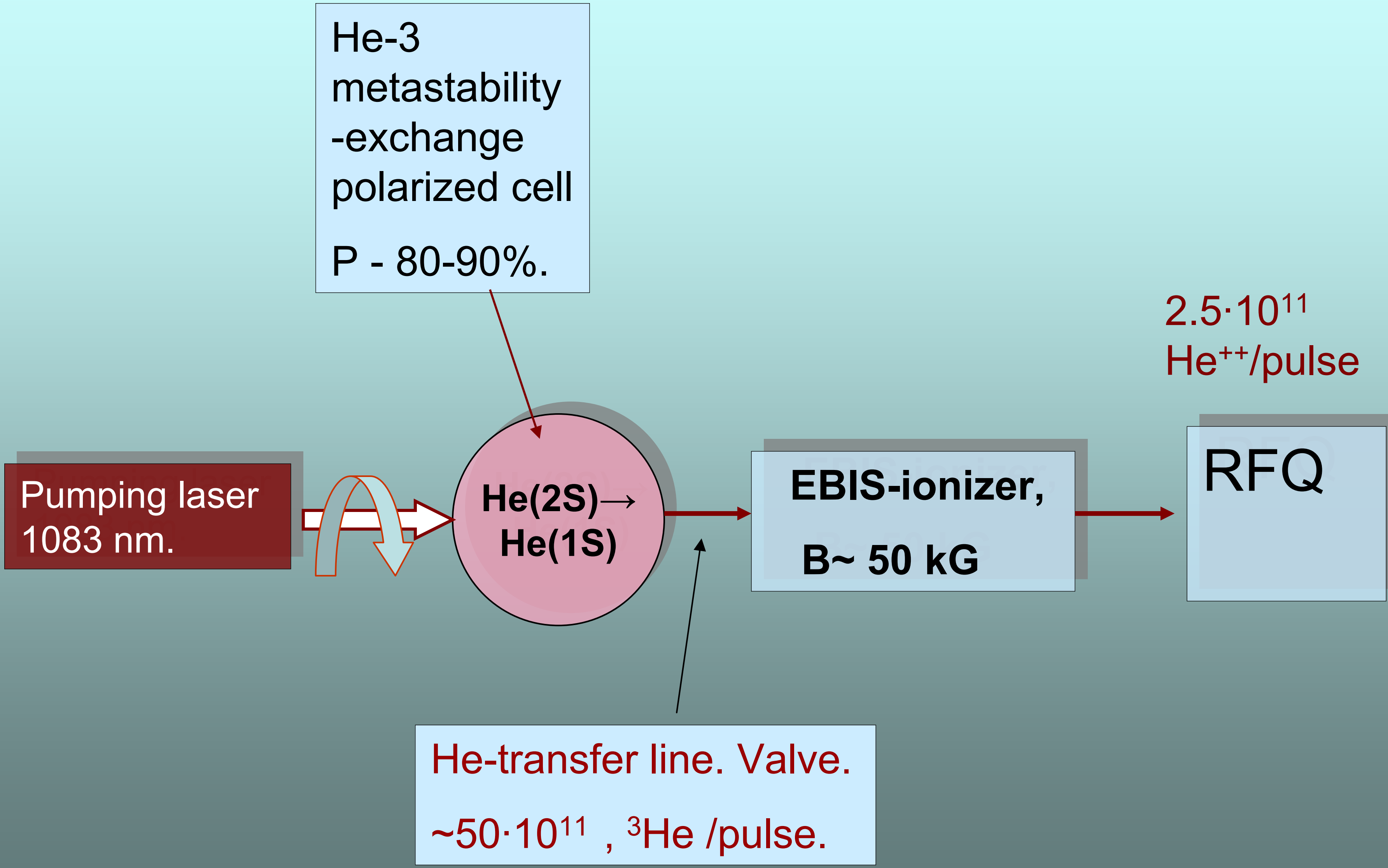
We propose the feasibility study of a new electron polarization technique based on the associative ionization of the alkali metal vapor by the resonant laser light.

If successful, this technique can be used for development of the very high intensity (of a few hundred mA) polarized electron source for the eRHIC complex.

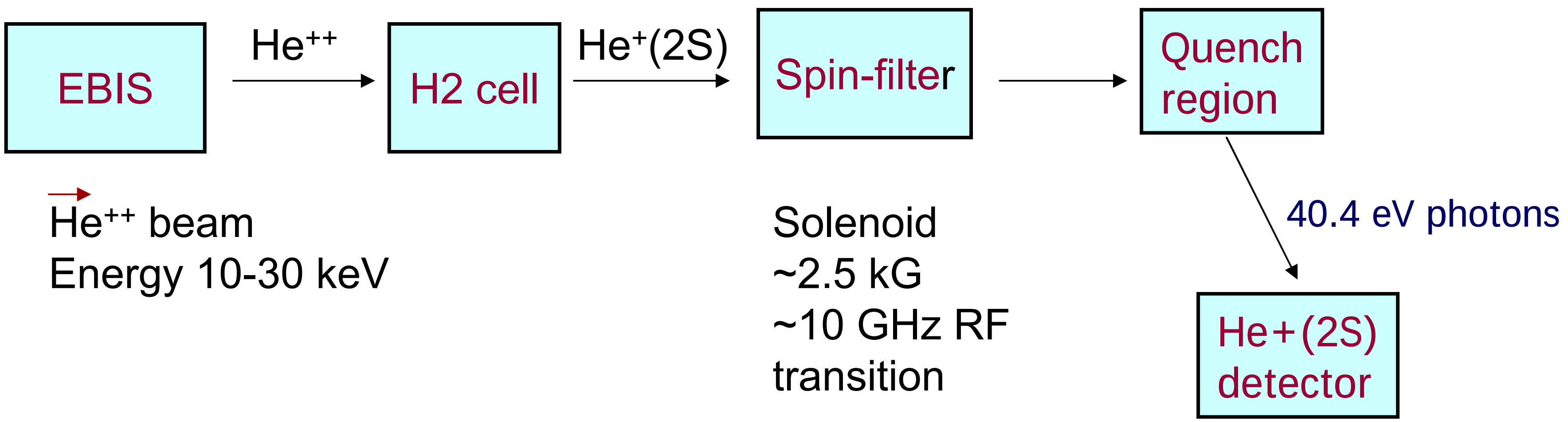
EBIS ionizer for polarized ^3He gas (proposal).

- Polarized ^3He gas is produced by a "metastability exchange" technique. P ~ 70-80% (pressure ~ 1 torr).
- ^3He gas is injected in the EBIS ionizer. Pulsed valve?
- The ionization in EBIS is produced in a 50 kG field.
- This field will greatly suppress the depolarization in the intermediate He^+ single charge state, $B_c(He^+) = 3.1$ kG
- The charge ratio $He^{++}/He^+ >> 1$.
- The number of He^{++} ions is limited to maximum charge which can be confined in EBIS (about $2.5 \cdot 10^{11}$ of $^3He^{++}$/store).
- It is sufficient to obtain ~10^{11} He^{++}/bunch in the RHIC.

EBIS ionizer for polarized ^{3}He gas (proposal).



^{3}He - Lamb-shift polarimeter.



The polarimeter development can be done with the He^{++} beam from the OPPIS ECR-source.

Polarized sources for RHIC, eRHIC, deutron EDM.

- Polarized H^- ion source and polarized H-jet ABS are presently in operation at RHIC.
- Polarized 3He++ ion source is under development for future exsperiments at RHIC, eRHIC.
- High-intensity polarized electron source is required for eRHIC (MIT, Bates proposal).
- Polarized D source is required for the deutron EDM exsperiment.

High-intensity H^-, $^3He^{++}$, electron sources are essential components of the RHIC, eRHIC physics, therefore strong source development program has to be established.

Polarized Sources and Targets PST 2007 Workshop

- Date: September 10-14, 2007
- Brookhaven National Laboratory
- Focussed discussions on:
- *Polarized Ion, Electron and He-3 polarized sources.*
- *Polarized internal targets.*
- *Polarimetry.*
- Invited speakers. Round – table discussions.
- Posters on status and summary talks.
- One day –lectures for students and BNL staff at BNL.
- Expected number of participants ~80 (~20 students).
  Registration fee - $250 (reduced for students).
- Publication in AIP Proceedings.

OPPIS with the "Fast Atomic Hydrogen Source"

- The ECR source has a comparatively low emission current density and high beam divergence. This limits further current increase and gives rise to inefficient use of the available laser power for optical pumping.

- In pulsed operation, suitable for application at high-energy accelerators and colliders, the ECR source limitations can be overcome by using instead a high brightness proton source outside the magnetic field.

- Atomic hydrogen beam current densities greater than 100 mA/cm^2 can be obtained at the Na jet ionizer location (about 180 cm from the source) by using a very high brightness fast atomic beam source developed at BINP, Novosibirsk, and tested in experiments at TRIUMF, where more than 10 mA polarized H^- and 50 mA proton beam intensity was demonstrated.

OPPIS with the “Fast Atomic Hydrogen Source”

- Higher polarization is also expected with the fast atomic beam source due to: a) elimination of neutralization in residual hydrogen; b) better Sona-still transition efficiency for the smaller ~ 1.5 cm diameter beam; c) use of higher ionizer field (up to 3.0 kG), while still keeping the beam emittance below 2.0 π mm·mrad, because of the smaller beam – 1.5 cm diameter.

- All these factors combined will further increase polarization in the pulsed OPPIS to:

  over 90% and the source intensity to over 10 mA.

  A new superconducting solenoid is required.

- The ECR-source replacement with an atomic hydrogen injector will provide the high intensity beam for polarized RHIC luminosity upgrade and for future eRHIC facilities.